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Value Engineering Synergies with Lean Six Sigma

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INSTITUTE FOR DEFENSE ANALYSES

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Executive Summary

Lean Six Sigma (LSS), its Design for Six Sigma (DFSS) variant, and Value Engineering (VE) were developed as business process improvement initiatives. This paper explores synergies between LSS, DFSS, and VE by identifying opportunities where they can be used together to increase the likelihood of obtaining improvements beyond the capability of just one approach.

The origins of these initiatives are different. VE originated in the industrial community during World War II when many manufacturers were forced to substitute materials and designs as a result of critical material shortages. LSS, as practiced in the Acquisition, Technology, and Logistics (AT&L) enterprise, is a combination of Lean, Six Sigma, and the Theory of Constraints (TOC). Each of these components also has different origins. Lean concepts can be traced to the evolution of the Toyota production system in the decades following World War II. Six Sigma has its genesis in the application of probability theory to statistical quality control. TOC represents a paradigm shift to improve the concepts of Just-In-Time (JIT) and Total Quality Management (TQM) to help stimulate the needed change. DFSS was developed to apply Six Sigma principles in the design phase.

These differences in origin lead to varying approaches to problem solving. Each initiative has different phases in its methodological approach:

- VE phases are orientation, information, function analysis, creative, evaluation, development, presentation, and implementation.
- LSS phases are define, measure, analyze, improve, and control.
- DFSS phases are define, measure, analyze, design (and optimize), and verify.

Business process improvement initiatives are also cyclical in nature. They evolve over time and can ultimately be replaced by processes that attempt to integrate specific attributes of older initiatives with the latest approaches and/or technologically enabled methodologies. Practitioners often differentiate their initiatives from others because of different origins, vocabulary, skills, and training; effectiveness in particular circumstances; and applicability to a specific problem. Unfortunately, these differentiations are not always important and can create organizational stovepipes that compete with one another. A successfully implemented methodology may not be the best and only one for every problem. Depending on the situation, integrating multiple approaches can provide valuable ideas and insights that augment the benefits of using the approaches separately.

Such synergies not only achieve better results, but also break down the organizational stovepipes that naturally occur when different offices are assigned responsibility for different problem-solving methods.

To examine these synergies, this paper describes the steps and activities within each of the methodological phases to provide the reader an appreciation for the logical flow of events that transition smoothly from one activity to another, working toward a solution. These descriptions are also used to identify similarities and differences and construct a cross-reference mapping between VE and LSS. The differences do not imply that one methodology is better than the other nor do they imply weaknesses. Instead, the differences indicate opportunities where both approaches may be used together to achieve better results.

How VE Can Benefit From LSS/DFSS

When LSS establishes goals, customer communication tools such as Likert scales, surveys, interviews, and focus groups are used. The VE counterpart, prioritize issues, is more focused on potential gains and feasibility of implementation. More formalized customer communication would help with decision-maker acceptance and approval of VE-generated recommendations.

LSS has a more detailed front-end process for data collection. Whereas the VE methodology simply states that the data should be collected, LSS creates and analyzes process maps, determines and prioritizes measurement systems, and establishes a formal data-collection plan. When VE finalizes the problem and facts, it often uses a Quality Function Deployment (QFD) tool to obtain a better understanding of the data and data sources in the context of the problem. The LSS's Supplies, Inputs, Process, Outputs, and Customers (SIPOC) framework is used to understand the entire process and where the problem fits in. VE's use of SIPOC could add insight to its function analysis process.

LSS also has a more disciplined approach toward implementation. VE simply creates an implementation plan and follows typical best practices to execute it. The LSS control plan is a formal activity designed to ensure that execution proceeds as planned and with specific metrics identified in advance. Furthermore, LSS includes a formal corrective action plan (sometimes as a separate process), which is not an unambiguous part of the VE methodology.

These differences represent areas where incorporating some LSS features would likely improve the VE methodology. These synergies would help formalize the VE process to reduce the likelihood of overlooking important information needed to help determine a course of action. They would also improve the likelihood of successful implementation.

How LSS/DFSS Can Benefit From VE

VE and LSS develop solutions to problems from different perspectives. Some of the most important distinctions are as follows:

- VE explicitly considers cost by collecting cost data and using cost models to make estimates for all functions over the life cycle. LSS reduces cost by eliminating waste and reducing variation through the use of statistical tools on process performance data. Exclusive emphasis on waste can be contradictory to reducing life-cycle cost. In VE, some waste can be tolerated if it is necessary to achieve a function that reduces the life-cycle cost. Safety stock to mitigate occasional supply disruption is a good example.
- In determining what should be changed, VE's function analysis identifies areas that cost more than they are worth, while LSS identifies root causes of problems or variations. VE's separation of function from implementation forces engineers to understand and deliver the requirements.
- For required functions that cost more than they are worth, VE uses structured brainstorming to determine alternative ways of performing them. LSS brainstorms to identify how to fix the root causes. Because functional thinking is not the common way of examining products or processes, VE augments the structured innovation process in a way that generates a large number of ideas. Enormous improvements are possible by determining which functions are really required and then determining how to best achieve them.
- VE develops solutions by evaluating the feasibility and effectiveness of the alternatives. LSS emphasizes solutions that eliminate waste and variation and sustain the achieved gains. VE eliminates waste in a different way. VE separates the costs required for basic function performance from those incurred for secondary functions to eliminate as many non-value-added secondary functions as possible, improve the value of the remaining ones, and still meet the customer requirements.
- An LSS focus on quick wins may preclude an in-depth analysis of the situation. Without analysis, projects can suboptimize or even work in opposition to one another. Using function analysis should prevent this suboptimization.

While DFSS is a proactive and anticipatory approach that helps evaluate and optimize conceptual, preliminary, and detailed designs, it is not an automatic process and does not replace skilled designers. Developing an effective design that does everything a user wants from a performance perspective and from the perspective of design considerations (e.g., supportability, maintainability, information assurance, availability, reliability, producibility may be applicable) while not costing too much or weighing too much will almost always benefit from the group perspectives and discussions of the Function

Analysis and Creative Phases of the VE job plan. VE links the customer requirements to the design to manage cost.

The literature on LSS and VE compares the strengths and weaknesses of the methodologies and highlights opportunities for collaboration. The literature examining these methodologies points to two primary areas where VE can contribute: scope and creative tools such as the Function Analysis System Technique (FAST) diagram. Experts are encouraging about the prospects for synergizing the methodologies, particularly in a process where a team can take advantage of respective strengths and avoid respective weaknesses.

The highest leverage points for VE contributions to LSS and DFSS over a life cycle vary by application. For a product, VE can provide benefit everywhere – from concept to decision to operations and support. For a service, VE is most applicable during conceptual design and operations. For a construction project, primary VE opportunities occur during preliminary and detailed design.

Recommendations

Both LSS and VE have unique attributes and perspectives for process improvement. Since certain problems may be more readily, effectively, or thoroughly managed by using one or both of these perspectives, exploring the full range of solution options is crucial. From the IDA authors' comparison of the methodological approaches and the examples of synergies discussed in the literature, we conclude that VE techniques are sometimes better equipped to lead to improvements or solutions complementary to those identified through a DMAIC/DFSS approach. These opportunities for synergy include

- **Function Analysis and the FAST diagram.** The disciplined use of function analysis is the principal feature that distinguishes the value methodology from other improvement methods. Function analysis challenges requirements by questioning the existing system and critical thinking. Function analysis subsequently develops innovative solutions to revised requirements.
- **Cost Focus.** VE only develops alternatives that provide the necessary functions. By examining only those functions that cost more than they are worth and identifying the total cost of each alternative, VE explicitly lowers cost and increases value.

VE does not take the place of LSS efforts, but it does present significant opportunities to enhance LSS-developed options. Therefore, the IDA authors recommend that LSS training be augmented to include the VE approach to function analysis, creativity, and associated elements of evaluation and development to identify candidate solutions as part of the Analyze and Improve Phases of DMAIC.

As far as DFSS is concerned, VE tools should be explicitly used in the process. They should be used in the Analyze Phase of DMADV to construct function views of the product or process to identify customer priorities and determine functional requirements. They should also be used in the Design Phase of DMADV to generate alternative design concepts and to modify component/subsystem preliminary and detailed designs to introduce new elements to the evaluation and optimization processes.

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1. Introduction

Lean Six Sigma (LSS), its Design for Six Sigma (DFSS) variant, and Value Engineering (VE) were developed as business process improvement initiatives. This paper explores synergies between LSS, DFSS, and VE by identifying opportunities where they can be used together to increase the likelihood of obtaining improvements beyond the capability of just one approach.

The origins of these initiatives are different. VE originated in the industrial community during World War II when critical material shortages forced many manufacturers to substitute materials and designs. When the General Electric (GE) Company found that many of the substitutes were providing equal or better performance at less cost, it launched an effort in 1947 to improve product efficiency by intentionally and systematically developing less costly alternatives. Lawrence D. Miles, a staff engineer for GE, led this effort. Miles combined several ideas and techniques to develop a successful methodological approach for ensuring value in a product. The concept quickly spread through private industry as the possibilities for large returns from relatively modest investments were recognized. This methodology was originally termed *Value Analysis (VA)* or *Value Control*.

LSS, as practiced in the Acquisition, Technology, and Logistics (AT&L) enterprise, is a combination of Lean, Six Sigma, and the Theory of Constraints (TOC). Each of these components also has different origins.

Lean concepts can be traced to the evolution of the Toyota production system in the decades following World War II.[1] They became established in the Western world in the 1980s and 1990s. “Lean thinking is the dynamic, knowledge-driven, and customer-focused process by which all people in a defined enterprise continuously eliminate waste with the goal of creating value.”[2] Value creation is a central concept in lean thinking to build robust, adaptive, flexible and responsive enterprises.

Six Sigma has its genesis in the application of probability theory to statistical quality control. The goal of Motorola’s Six Sigma initiative was to identify and reduce all

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[1] Refer, for example, to James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine That Changed the World* (New York: Rawson Associates, 1990).

[2] Earl M. Murman et al., *Lean Enterprise Value: Insights from MIT’s Lean Aerospace Initiative* (Houndmills, Basingstoke, Hampshire RG21 6XS, Great Britain: Palgrave, 2002), 90.

sources of product variation—machines, materials, methods, measurement systems, the environment, and the people—in the process. The idea is not new. It can be traced to the introduction of lean thinking and Total Quality Management (TQM). At a technical level, Six Sigma is aimed at achieving virtually defect-free operations, where parts or components can be built to very exacting performance specifications. Underlying Six Sigma as a statistical concept[3] is the construct of standard deviation, a measure of dispersions around the mean. Reducing variation to the Six Sigma level denotes reaching a performance level of 99.99966% perfection (3.4 defects or non-conformance per million opportunities[4]). This level of performance means virtually defect-free production, where a defect is defined as any instance or event in which the product fails to meet a customer requirement.

TOC was developed by Eliyahu M. Goldratt, a physicist by education, in a series of publications over the past 2 decades.[5] According to Goldratt, TOC represents a paradigm shift to improve the concepts of Just-in-Time (JIT) and TQM to help stimulate the needed change. The important contribution of TOC has been its recognition at a conceptual level that systems should be viewed as “chains” of interdependence and that systems contain leverage points—constraints—where proactive change initiatives can deliver large positive effects on overall system performance.

DFSS was developed to apply Six Sigma principles in product design. A common rule of thumb is that only 20% of cost can be affected by improving the efficiency of processes while 80% of costs are locked in during design. Consequently, improving the design early in the life cycle, when the design flexibility is highest, has far greater leverage.[6] Historically, DFSS was created in part because Six Sigma organizations found that they could not optimize products (or their manufacturing process) past three or four sigma without fundamentally redesigning the product. This means that “Six Sigma” levels of performance have to be “built-in” or “by design.” While Six Sigma requires a process to be in place and functioning, the objective of DFSS is to determine the needs of the customers and the business and to drive those needs into the product/process solution. It is product/process generation as opposed to process improvement. DFSS aims to create a product/process by optimally building the efficiencies of Six Sigma methodology into the product/process before implementation.

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[3] Industry has a long history of using statistics. See, for example, Gerald J. Hahn, *The Role of Statistics in Business and Industry* (Hoboken, NJ: John Wiley and Sons, 2008).

[4] Defects per million opportunities indicates how many defects would be observed if an activity were repeated a million times.

[5] See for example Eliyahu M. Goldratt, *Theory of Constraints* (Croton-on-Hudson, NY: North River Press, Inc., 1990).

[6] For example, Hinckley states that the cost of change is 100 times higher during production tooling than during conceptual design in C. Martin Hinckley, *Managing Product Complexity, It’s Just a Matter of Time,* Report No. SAND-98-8564C (Livermore, CA: Sandia National Laboratories, June 1, 1998).

Business process improvement initiatives are also cyclical in nature. They evolve over time and can ultimately be replaced by processes that attempt to integrate specific attributes of older initiatives with the latest approaches and/or technologically enabled methodologies. Practitioners often differentiate their initiatives from others because of different origins, vocabulary, skills, and training; effectiveness in particular circumstances; and applicability to a specific problem. Unfortunately, these differentiations are not always important, and can create organizational stovepipes that compete with one another. A successfully implemented methodology may not be the best and only one for every problem. Depending on the situation, integrating multiple approaches can provide valuable ideas and insights that augment the benefits of using the approaches separately. Such synergies not only achieve better results, but also break down the organizational stovepipes that naturally occur when different offices are assigned responsibility for different problem-solving methods.

To examine these synergies, this paper is organized as follows:

- Chapter 2 discusses the VE methodology.
- Chapter 3 discusses the LSS and DFSS approaches.
- Chapter 4 cross-references the methodologies and identifies ways in which one methodology can benefit the other.
- Chapter 5 examines opportunities for synergy in more detail.
- Chapter 6 presents conclusions.

2. The Value Engineering (VE) Methodology

The VE methodology, also referred to as the job plan, is divided into eight phases:

- Orientation
- Information
- Function Analysis
- Creative
- Evaluation
- Development
- Presentation
- Implementation

The following sections describe each phase and its purpose. Figure 1 graphically depicts the phases and the principal steps within the job plan. The application of the methodology to a problem is often referred to as a value study. Except for the Orientation and Implementation Phases, the value study typically occurs in a workshop setting.

A. Orientation Phase

The Orientation Phase refines the problem and prepares for the workshop. The value study and workshop have a greater likelihood of success if ample preparation time has been devoted to determining what aspects of the problem will be addressed in detail and preparing everything needed for the analysis. Throughout these preparatory activities, a close working relationship between the study team leader and the manager sponsoring the project contributes significantly to a successful outcome.

The following subsections describe the activities during the Orientation Phase. The activities can occur in an order different from that shown here. Some activities can also be repeated or occur simultaneously if other people are supporting the team leader's efforts.

The first five activities represent one systematic approach to refining the problem. The job plan can also be used entirely in the context of the Orientation Phase as a formal project planning tool.

1. Identify the Specific Issues Addressed

The first step in a project is to identify a problem. The problem area should be divided into its constituent elements. Each element should represent a specific issue that can be addressed and resolved.

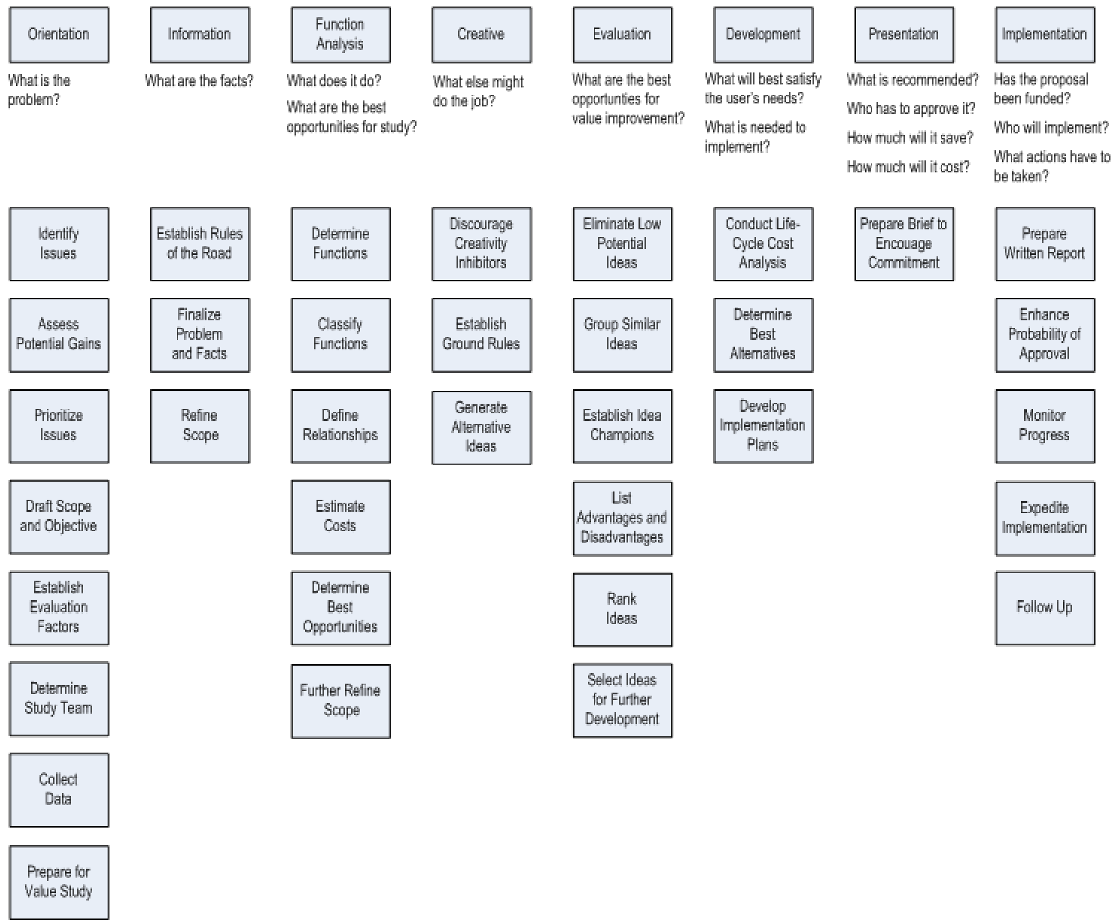

Figure 1. VE Job Plan

Consider, for example, the Navy's Standard Missile program. The program office was faced with a situation in which missile demand was level but the price was increasing while budgets were decreasing. Of the three controllable constituent elements of missile cost (production, development, and logistics), production costs were determined to be the most fruitful area for further investigation. In fact, the production costs could readily be broken down into smaller and smaller constituent elements to form the basis of individual VE projects.[7]

[7] See Roland Blocksom, "STANDARD Missile Value Engineering (VE) Program—A Best Practices Role Model," *Defense AT&L Magazine*, July–August 2004, 41–45.

Identifying specific issues is accomplished by developing an understanding of the sponsor's problems and avoiding areas that the sponsor would not be able change because of political, cultural, or feasibility implications. Once the problems are understood, they can be addressed at varying levels of detail. At this stage of the VE methodology, an adequate amount of detail is needed to obtain a general grasp of potential VE projects for the issue under consideration.

2. Assess the Potential Gains for Resolving Each of These Issues

The purpose of this activity is to identify issues that have the greatest potential for value improvement. Solution areas postulated this early in the process should be used only for this step because they could inhibit creative activities applied later in the job plan to generate alternatives.

The assessment of the potential gains for resolving issues should be as quantitative as possible; however, at this stage of the analysis, estimates will be crude. While developing a reasonable understanding of the costs involved may not be too difficult, savings estimates are much more problematic since no solution has been developed. Some information is normally available, however, and should be used to assess the problems and potential gains.

In the Standard Missile example, one of the VE projects involved the transceiver assembly. One potential solution was to replace the assembly with a less costly one. Savings estimates were difficult to obtain because the characteristics of the new assembly were unknown. Another potential solution involved developing a greater level of aggregation. Here, savings would be generated by eliminating tests.

3. Prioritize Issues

While prioritization should weigh the potential gains, it should also consider the likelihood of determining an effective solution and the feasibility of implementing that solution. In the case of the transceiver assembly for the Standard Missile, the second potential solution (developing a greater level of aggregation) was much more straightforward and had a higher likelihood of success than the first potential solution (replacing the assembly with a less costly alternative).

Understanding the importance of the problem to the project sponsor is also a key factor. If the sponsor is determined to solve the problem, the likelihood of success is enhanced. Once management commitment is understood, a useful question to ask is why the problem had not already been solved.

The answer to this question may identify roadblocks to be overcome. Knowing what stands in the way of a solution is another important consideration for the prioritization process. Finally, other benefits, such as performance improvement, should be considered.

4. Draft a Scope and an Objective for the Value Study

The study team's efficiency is significantly enhanced when limits are established in advance. More than one of the constituent problem elements can be included in the scope. The study sponsor must approve the scope. Ultimately, the scope and the objective will be finalized in the Information Phase. This preliminary work will expedite that process.

5. Establish Evaluation Factors

Targets for improvement should be challenging, and evaluation factors must be measurable. These factors determine the relative importance of the ideas and the potential solutions generated by the team. The study sponsor must approve the improvement targets and the evaluation factors.[8]

6. Determine Team Composition

Essential team member characteristics include technical or functional expertise, problem-solving and decision-making abilities, and interpersonal skills. Participants should be team players who are willing to share responsibilities and accountability while working together toward a common objective. The team should also be multidisciplinary and include all factions affected by the study to ensure that relevant stakeholders and experts are included. Kaufman suggests that because gathering all the information needed to make a "no-risk decision" is impossible, a multidisciplinary team should provide enough different perspectives to at least substantially reduce the risk.[9]

The ideal team size is 5 to 7 people. A team with more than 10 participants is difficult to control.[10] After the team members have been selected, the team leader should prepare a management memorandum to be sent to all team members. This memorandum should

- Emphasize the importance of their role,
- Approve the necessary time commitment,
- Authorize sharing of any objective and subjective data that bear on the problem, and
- Identify the team leader.

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[8] In manufacturing-oriented workshops, criteria are not usually selected until competing alternatives have been developed.

[9] J. Jerry Kaufman, *Value Engineering for the Practitioner* (Raleigh, NC: North Carolina State University, 1990), 2–4.

[10] If more participants are needed, the use of on-call experts should be considered.

7. Collect Data

The team leader organizes the data-collection activities in advance of the workshop. As more information is brought to bear on the problem, the probability of substantial benefit increases. To increase the study team's productivity, collecting as much data as possible in advance is crucial. The data-collection effort benefits by having the entire team involved. In fact, some team members may have key information readily available.

The data should be as tangible and quantitative as possible and should include anything potentially useful for understanding the problem, developing solutions, and evaluating pros and cons of the solutions. The paramount considerations are getting enough facts and getting them from reliable sources.

In addition to possessing specific knowledge of the item or process under study, the team should have all available information concerning the technologies involved and should be aware of the latest technical developments pertinent to the subject being reviewed.

Developing and ranking alternative solutions depend on having reliable cost data. Data on customer and user attitudes also plays a key role. Part of the VE study aims at identifying which aspect of the task holds the greatest potential for payoff. This potential for payoff is a function of the importance to the user and customer. The seriousness of user-perceived faults is also a factor in prioritization.

8. Prepare Logistically for the Value Study

The value study facilitator, who may also be the team leader, prepares the team to participate in the study. He/she is normally certified by the Society of American Value Engineers (SAVE), the VE professional society. The two levels of certification are Certified Value Specialist and Associate Value Specialist.

Initially, brief meetings with potential team members can be held to determine who should participate. The team leader/facilitator should

- Ensure participants know what data they should bring,
- Set up study facilities and prepare materials (easels, markers, and so forth),
- Set up a kickoff briefing and results briefing with management, and
- Obtain an example of a study item for the team to use.

Pre-study reading materials should be identified and distributed to the participants. Materials that can be assigned as advanced reading include the agenda, operational requirements documents, design documents (drawings and specifications), performance requirements, production quantities, inventory data, failure/quality information, and others necessary to ensure consistent understanding of the issues.

A pre-workshop orientation meeting might be useful to

- Review workshop procedures;
- Acquaint the team with the problem and read-ahead material;
- Eliminate incorrect preconceived notions about VE, the job plan, the workshop, the problem, the people, and so forth;
- Jump-start the team-building process;
- Clarify acceptable and unacceptable behaviors (rules of the road) for team-member participation; and
- Identify additional information needs.

The date should be set reasonably far in advance (4 to 6 weeks) to allow personnel to arrange their schedules around the study. When a workshop setting is used, the value study typically takes 3 to 5 days.[11]

B. Information Phase

The Information Phase finalizes the scope of the issues to be addressed, the targets for improvement, and the evaluation factors; collects and analyzes the data; and builds cohesion among team members. In many respects, the Information Phase completes the activities begun in the Orientation Phase. This work is normally conducted in a workshop setting and is often the first opportunity for all team members to come together (if no pre-workshop orientation meeting was scheduled). Consequently, the Information Phase should be used to motivate the team to work toward a common goal. Finalizing the scope of the issues to be addressed, the targets for improvement, the evaluation factors, and the data collection and analysis efforts are ideal endeavors for building team cohesion. The following subsections describe the activities during the Information Phase.

1. Establish Workshop Rules of the Road

This activity begins the team-building process; therefore, the facilitator should ensure that all team members know each other and their relevant backgrounds, authority, and expertise. Some authors suggest that team-building exercises should be conducted at the beginning of the workshop.[12] The following guidelines should be established to set the stage for an effective working relationship among the team members:

- Share workload equally whenever possible.
- Be willing to admit that you do not know something, but strive to get the answer. Do not be afraid to make mistakes.

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[11] Three days may be sufficient for small studies, but 5 days are more common. To avoid keeping the team together for 5 consecutive days, a separate 2-day workshop can be held for the Development and Presentation Phases.

[12] Robert B. Stewart, *Fundamentals of Value Methodology* (Bloomington, IN: Xlibris Corporation, 2005), 113–118.

- Stay focused and follow the basic problem-solving steps. Do not waste time discussing whether you should use each step; complete the steps and conduct an evaluation after you have completed the entire workshop. Be sure that you understand the approach and its purpose, including the reason for each step and the technique being applied. Keep the discussions relevant.
- Work together as a team. Do not force your solutions—sell them! A problem can have multiple solutions.
- Be a good listener; do not interrupt people or criticize what they say.
- Keep an open mind and do not be a roadblock.
- Be enthusiastic about the project and what it is that you are doing.
- Do not attempt to take over as a team leader; be as helpful as possible. The leader already has a difficult job in guiding, controlling, and coordinating the overall effort.
- Accept conflicts as necessary and desirable. Do not suppress or ignore them. Work through them openly as a team.
- Respect individual differences. Do not push each other to conform to central ideas or ways of thinking.
- Work hard. Keep the team climate free, open, and supportive.
- Fully use individual and team abilities, knowledge, and experience.
- Accept and give advice, counsel, and support to each other while recognizing individual accountability and specialization.

2. Finalize the Problem and the Associated Facts

Before starting the analysis, the team should finalize the problem and ensure mutual understanding. This process involves discussing the problem so that all team members achieve a consistent understanding of the issues. Work on specifics, not generalities. This approach also serves as a useful team-building exercise.

The VE team should begin collecting information before the start of the workshop. If possible, this information should include physical objects (e.g., parts) that demonstrate the problem. When supported facts cannot be obtained, the opinions of knowledgeable people can be used. These people can be invited to participate in the workshop, or their opinions can be documented. The Information Phase is typically used to familiarize the team members with the data and the data sources in the context of defining the problem. The keys are

- Getting up-to-date facts from the best sources,
- Separating facts from opinion, and
- Questioning assumptions.

Having all of the pertinent information creates an ideal situation, but missing information should not preclude the performance of the VE effort.

Quality Function Deployment (QFD) is a structured approach to translating customer needs or requirements into specific plans to produce products or develop processes to meet those needs.[13] Ball suggests that QFD techniques can be beneficial in the Information Phase because a better understanding of customer requirements leads to a better understanding of product function.[14]

3. Refine the Scope

The problem at hand often requires more time than the workshop schedule permits. In these cases, the problem should be rescoped to ensure that the most important elements are examined during the workshop. Plans for continuing the effort on the balance of the problem can be made at the end of the workshop.

Once the scope is determined and the final set of facts are collected from the best possible data sources, targets for improvement and evaluation factors should be reexamined and finalized. The study sponsor should approve any changes.

C. Function Analysis Phase[15]

The Function Analysis Phase identifies the most beneficial areas for study. The analytical efforts in this phase form the foundation of the job plan. The disciplined use of function analysis distinguishes the value methodology from other improvement methods. The following subsections describe the activities during the Function Analysis Phase.[16]

1. Determine the Functions

For the product or process under study, this activity encompasses determining 40 to 60 functions that are performed by the product, the process, or any of the parts or labor operations. Functions are defined for every element of the product or process that consumes resources. The functions are typically recorded on adhesive-backed cards for later manipulation.

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[13] Adapted from Kenneth Crow, *Customer-Focused Development with QFD* (Palos Verdes, CA: DRM Associates, 2002). Available: http://www.npd-solutions.com/qfd.html. Additional articles can be found in Robert A. Hunt, and Fernando B. Xavier, "The Leading Edge in Strategic QFD," *International Journal of Quality & Reliability Management* 20, no. 1 (2003): 56–73.

[14] Henry A Ball, "Value Methodology—The Link for Modern Management Improvement Tools," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003).

[15] Some material in this section was adapted from information in Army Pamphlet 11-3, *Value Engineering* (n.d.) and DoD Handbook 4245.8-H, *Value Engineering* (March 1986).

[16] These activities are adapted from SAVE International, *Function: Definition and Analysis* (October 1998), http://www.value-eng.org/pdf_docs/monographs/funcmono.pdf. They are consistent with those listed in SAVE International, *Value Standard and Body of Knowledge* (SAVE International Standard, June 2007), http://www.scribd.com/doc/15563084/Value-Standard-and-Body-of-Knowledge.

A function is defined as "the original intent or purpose that a product, service, or process is expected to perform."[17] Unstructured attempts to define the function(s) of an item will usually result in several concepts described in many words. Such an approach is not amenable to quantification. In VE, a function must be defined by two words: an active verb and a measurable noun:

- The verb should answer the question, "What does it do?" For example, it may generate, shoot, detect, emit, protect, or launch. This approach is a radical departure from traditional cost-reduction efforts because it focuses attention on the required action rather than the design. The traditional approaches ask the question, "What is it?" and then concentrate on making the same item less expensive by answering the question, "How do we reduce the cost of this design?"
- The noun answers the question, "What does it do this to?" The noun tells what is acted upon (e.g., electricity, bullets, movement, radiation, facilities, or missiles). It must be measurable or at least understood in measurable terms since a specific value must be assigned to it during the later evaluation process that relates cost to function.

A measurable noun, together with an active verb, provides a description of a work function (e.g., generate electricity, shoot bullets, detect movement, and so forth).

A work function establishes quantitative statements. Functional definitions containing a verb and a non-measurable noun are classified as sell functions. They establish qualitative statements (e.g., improve appearance, decrease effect, increase convenience, and so forth). Providing the correct level of function definition is important. For example, the function of a water service line to a building could be stated as "provide service." "Service," not being readily measurable, is not amenable to determining alternatives. On the other hand, if the function of the line was stated as "conduct fluid," the noun in the definition is measurable, and the alternatives dependent upon the amount of fluid being transported can be readily determined.

The system of defining a function in two words, a verb and a noun, is known as two-word abridgment. The advantages of this system are that it

- Forces brevity. If a function cannot be defined in two words, insufficient information is known about the problem or the segment of the problem being defined is too large.
- Avoids combining functions and defining more than one simple function. By using only two words, the problem is broken down into its simplest element.

[17] SAVE International, *Value Standard and Body of Knowledge* (SAVE International Standard, June 2007), 28, http://www.scribd.com/doc/15563084/Value-Standard-and-Body-of-Knowledge.

- Aids in achieving the broadest level of dissociation from specifics. When only two words are used, the possibility of faulty communication or misunderstanding is minimized.
- Focuses on function rather than on the item.
- Encourages creativity.
- Frees the mind from specific configurations.
- Enables the determination of unnecessary costs.
- Facilitates comparison.

2. Classify the Functions

The second major activity in the Function Analysis Phase is to group the functions into two categories: basic and secondary.

The basic function is the intent and purpose of an item, product, or process and answers the question, "What must it do?" Basic functions have or use value. A basic function defines the specific purpose(s) for which a product, facility, or service exists and conveys a sense of "need."[18]

A product or service can possess more than one basic function, determined by considering the user's needs. A non-load-bearing exterior wall might be initially defined by the function description "enclose space." However, further function analysis determines that, for this particular wall, two basic functions are more definitive than the initial one: "secure area" and "shield interior." Both functions answer the question, "What does it do?"

Secondary functions answer the question "What else does it do?" Secondary functions are support functions and usually result from the particular design configuration. Generally, secondary functions contribute greatly to cost and may or may not be essential to the performance of the primary function. They support the basic function and result from the specific design approach to achieve the basic function. [19]

As methods or design approaches to achieve the basic function are changed, secondary functions can also change. Three kinds of secondary functions are as follows:

1. **Required secondary functions.** These functions are necessary in a product or project to perform the basic function. For example, battery-operated flashlights and kerosene lanterns perform the basic function of producing light. A required secondary function, however, in the flashlight is to "conduct current" while the equivalent secondary function in the lantern is to "conduct fluid."

[18] Ibid.

[19] Ibid.

2. **Aesthetic secondary functions.** These functions add beauty or decor to the product or project and are generally associated with "sell functions." For example, the colors of paint available for a car could be an aesthetic secondary function.
3. **Unwanted secondary functions.** These functions, by definition, are not wanted while the product is performing the basic or secondary function(s). For example, while the kerosene lantern performs the basic function of producing light, an unwanted secondary function is that it "produces odor."[20]

Secondary functions that lend esteem value (convenience, user satisfaction, and appearance) are permissible only if they are necessary to permit the design or item to work or sell. These functions sometimes play an important part in the marketing or acceptance of a design or product. VA separates costs required for basic function performance from those incurred for secondary functions to eliminate as many non-value-added secondary functions as possible, improve the value of the remaining functions, and still provide the appeal necessary to permit the design or product to sell.

3. Develop Function Relationships

Two principal techniques have been developed to create a better understanding of function relationships: a function hierarchy logic model and the Function Analysis System Technique (FAST).[21] This document concentrates on the classical FAST approach and the use of the FAST diagram.[22] FAST was developed by Charles W. Bytheway of the Sperry Rand Corporation and introduced in a paper presented at the 1965 National Conference of the Society of American Value Engineers in Boston. Since then, FAST has been widely used by government agencies, private firms, and VE consultants. FAST is particularly applicable to a total project, program, or process requiring interrelated steps or a series of actions. Figure 2 illustrates a classical FAST diagram.

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[20] James D. Bolton, Don J. Gerhart, and Michael P. Holt, *Value Methodology: A Pocket Guide to Reduce Cost and Improve Value Through Function Analysis* (Lawrence, MA: GOAL/QPC, 2008), 46.

[21] These two approaches are described on an overview basis and illustrated using the same project in Save International, *Function Relationships – An Overview* (SAVE International Monograph, 1999).

[22] Technical FAST and customer FAST follow slightly different rules and formats. Additional information about the Function Hierarchy Logic model can be found in SAVE International, *Function Logic Models* (n.d.), http://www.value-eng.org/pdf_docs/monographs/funclogic.pdf. The equivalent publication on FAST is Save International, Functional Analysis Systems Techniques – The Basics (SAVE International Monograph (n.d.)), http://www.value-eng.org/pdf_docs/monographs/FAbasics.pdf. The Army has published some FAST training material: *Function Analysis System Technique (FAST) Student Guide*, prepared by Nomura Enterprise, Inc., and J. J. Kaufman Associates, Inc., for the U.S. Army Industrial Engineering Activity, Rock Island, Illinois. The approach outlined in this section most closely follows J. Jerry Kaufman, *Value Engineering for the Practitioner* (Raleigh, NC: North Carolina State University, 1990).

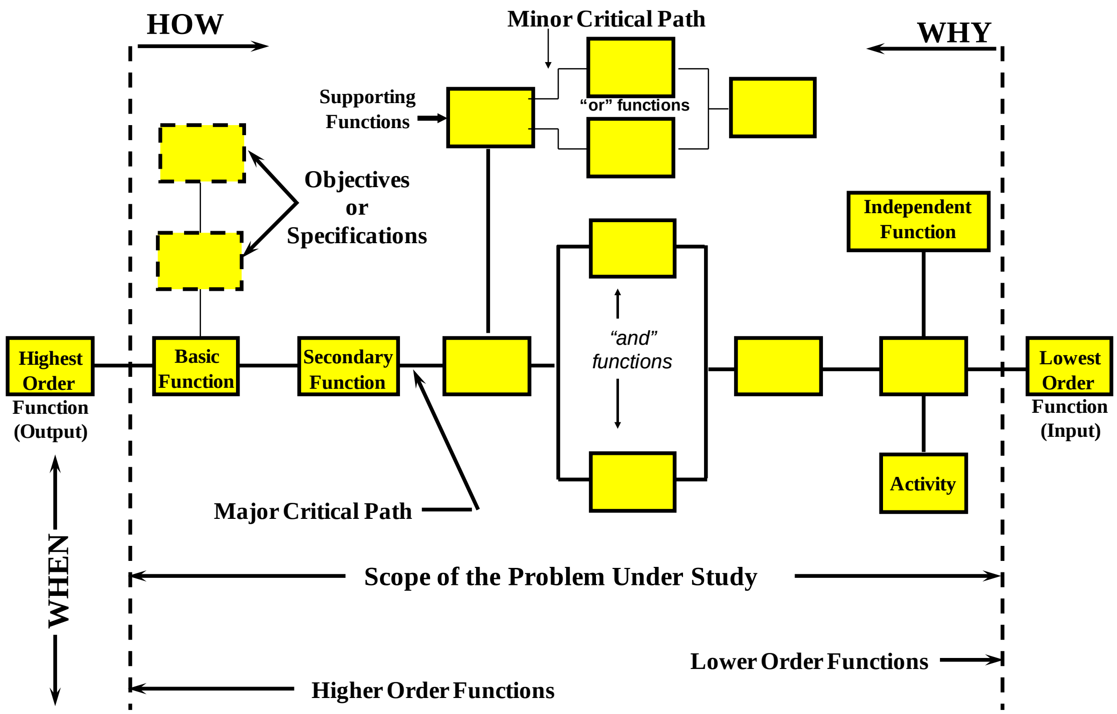

Figure 2. Illustrative Classical FAST Diagram

The basic classical FAST steps are as follows:

- **Step 1:** Determine the highest order function. "The objective of the value study is called the Highest Order Function(s) and is located to the left of the basic function(s) and outside the left scope line."23 Determining the highest order function is not always an easy process. For instance, the most offered highest order function for a cigarette lighter is "lights cigarettes." This characterization, however, immediately raises the obvious question, "What about pipes and cigars?" An alternative might then be "generates flame." However, the electrical resistance lighter in a car only "emits energy." The thought process must focus in either one direction or another to develop a multiplicity of two-word abridgements from which one or more levels can be chosen as the level of the basic functions to be studied.
- **Step 2:** Identify the basic functions. Select the basic functions that directly answer the question, "How does the product or process perform the highest order function?" If all direct answers are not among the existing basic functions, create a new one. All of these basic functions should be included in the first column to the right of the higher order function.

[23] Robert B. Stewart, *Fundamentals of Value Methodology* (Bloomington, IN: Xlibris Corporation, 2005), 182.

- **Step 3:** Expand the FAST diagram. Keep asking how the function is performed from the viewpoint of a user. Most answers will be found among the existing functions. Add second, third level, and lesser functions as needed to the right of the basic functions but do not expand a function unless the “how” question is answered by two or more functions. Repeating the “how” question in this way is sometimes called the “ladder of abstraction” method. It is a thought-forcing process. Because using more than one definition can generate more creative ideas, this approach leads to greater fluency (more ideas), greater flexibility (variety of ideas), and improved function understanding of the problem. It generates critical paths for achieving the basic functions.
- **Step 4:** Identify the supporting functions. Supporting functions do not depend on another function. They are placed above a critical path and usually are needed to achieve the performance levels specified for the critical path function they support. The supporting functions above the critical path and the activities below the critical path are the result of answering the “when” question for a function on the critical path. A supporting function can have its own minor critical path.
- **Step 5:** Verify the FAST diagram. The FAST diagram is verified by driving one’s thinking up the ladder of abstraction. Asking “why” raises the level, making the function description more general. In practice, the desired level is one that makes possible the largest number of feasible alternatives. Since the higher levels are more inclusive and afford more opportunities, the desired level is the highest level that includes applicable, achievable alternatives. A practical limit to the “why” direction is the highest level at which the practitioner is able to make changes. If the level selected is too low, alternatives can be restricted to those that resemble the existing design. If the level selected is too high, achievable alternatives can be obscured, and alternatives that are beyond the scope of effort might be suggested.

4. Estimate the Cost of Performing Each Function

All VE efforts include some type of economic analysis that identifies areas of VE opportunity and provides a monetary base from which the economic impact of the effort can be determined. The prerequisite for any economic analysis is reliable and appropriate cost data. Consequently, the VE effort should use the services of one or more individuals who are skilled in estimating, developing, and analyzing cost data. The cost of the original or present method of performing the function (i.e., the cost for each block of the FAST diagram) is determined as carefully and precisely as possible given the time constraints for preparing the estimate.

The accuracy of a cost estimate for a product depends on the

- "Maturity" of the item,
- Availability of detailed specifications and drawings, and
- Availability of historical cost data.

Similarly, the accuracy of a cost estimate for a service depends on the

- People involved,
- Time spent performing the service,
- Waiting time, and
- Direct, indirect, and overhead labor and material costs.

In some cases, a VE study will involve both products and services.

5. Determine the Best Opportunities for Improvement

The objective of this activity is to select functions for continued analyses. It is often accomplished by comparing function worth to function cost, where value is defined by the ratio of worth to cost (or cost to worth).[24] *Function worth* is defined as the lowest cost to perform the function without regard to consequences.

Thus, the concept of function worth leads the VE effort to study those functions that will be most worthwhile and provides a reference point to compare alternatives. It can even be used as a psychological incentive to discourage prematurely stopping the VE effort before all of the alternatives are considered.

Determining the worth of every function is usually not necessary. Cost data aid in determining the priority of effort. Because significant savings potential in low-cost areas may not be a worthwhile pursuit and high-cost areas may be indicative of poor value, the latter are prime candidates for initial function worth determination. Costs are usually distributed in accordance with Pareto's Law of Maldistribution: a few areas, "the significant few," (generally 20% or less) represent most (80% or more) of the cost. Conversely, 80% of the items, "the insignificant many," represent only 20% of total costs. Figure 3 illustrates this relationship.

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[24] In practice, determining function worth is often difficult. As an alternative, total function cost can be distributed in a matrix whose rows are the functions and whose columns are components of a product or departments in a service or process scenario. Best opportunities for improvement are sought among the highest cost functions. The relative worth of components can also be inferred from a customer's relative value of design functions. An interesting example of using QFD to do this can be found in K. Ishii and S. Kmenta, *Life-cycle Cost Drivers and Functional Worth*, Project Report for ME317: Design for Manufacturing, Department of Mechanical Engineering (Palo Alto, CA: Stanford University, n.d.).

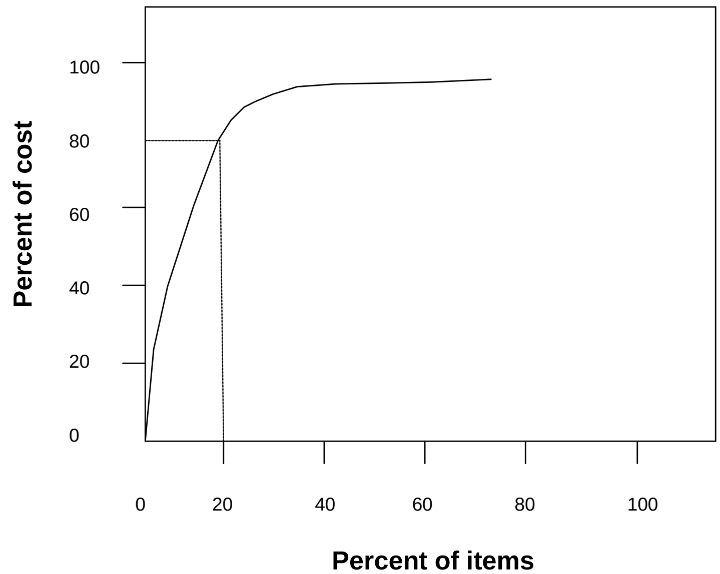

Figure 3. Pareto's Law of Maldistribution

A technique for developing the worth of functions, conceived in the early days of VA and still effective today, compares the selected function to the simplest method or product that can be imagined to achieve the same result. One increasingly popular technique for assigning worth to functions ascertains the primary material cost associated with the function.[25]

The value calculation can be done in many ways. For example, some workshop facilitators use a ratio of "percent relative importance" to "percent of cost." In this approach, all functions are evaluated pairwise, with different numbers assigned to reflect the relative importance of the two functions being compared (e.g., 3 may mean a large difference in importance, 1 may mean a small difference in importance). A relative importance is calculated for each function individually as the sum of the relative importance scores that function received when it was ranked higher than another function in the pairwise comparisons. The "percent relative importance" is calculated by converting the individual function's relative importance scores to a percentage of the total. The "percent of cost" is the cost of a function relative to the total cost of all functions.[26] Snodgrass[27] suggests another approach based on high, medium, and low scores for function acceptance, function cost, and function importance.

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[25] SAVE International, *Function: Definition and Analysis* (October 1998), http://www.value-eng.org/pdf_docs/monographs/funcmono.pdf.

[26] A more complete description can be found in Arthur E. Mudge, *Value Engineering – A Systematic Approach* (Pittsburgh, PA: J. Pohl Associates, 1989), 68–74.

[27] Thomas J. Snodgrass, "Function Analysis and Quality Management," in *SAVE International 33rd Annual Conference Proceedings* (1993).

Whatever approach is used, the best opportunities for improvement are determined by improving functions that have excessively low ratios of worth to cost (or high ratios of cost to worth). This ratio is referred to as the value index.

6. Refine Study Scope

The final activity in the Function Analysis Phase refines the study scope to reflect any changes that have taken place.

D. Creative Phase

The Creative Phase develops ideas for alternative ways to perform each function selected for further study. The two approaches to solving a problem are analytical and creative. In the analytical approach, the problem is stated, and a direct, step-by-step approach to the solution is taken. An analytical problem frequently has only one solution that will work. The analytical approach should *not* be used in the Creative Phase. The creative approach is an idea-producing process specifically intended to generate a number of solutions, each of which solves the problem at hand. All solutions could work, but one is better than the others. It is the optimum solution among those available. Once a list of potential solutions is generated, determining the best value solution is an analytical process conducted in the latter phases of the job plan.

Creative problem-solving techniques are an indispensable ingredient of effective VE. By using the expertise and experience of the study team members, some new ideas will be developed. The synergistic effect of combining the expertise and experience of all team members will lead to a far greater number of possibilities. The following sub-sections describe the activities during the Creative Phase (also called the Speculation Phase).

1. Discourage Creativity Inhibitors

For these processes to work well, the team must avoid mental attitudes that hinder creativity. The facilitator should point out creativity inhibitors to the team. Awareness of these inhibitors encourages people to overcome them. Parker identifies the following as common habitual, perceptual, cultural, and emotional blocks to creativity:[28]

- Habitual blocks
  - Continuing to use "tried and true" procedures even though new and better ones are available
  - Rejecting alternative solutions that are incompatible with habitual solutions

[28] Donald E. Parker, *Value Engineering Theory*, rev. ed. (Washington, D.C.: The Lawrence D. Miles Value Foundation, 1998), 93.

- Lacking a positive outlook, lacking effort, conformity to custom, and reliance on authority

- Perceptual blocks
  - Failure to use all the senses for observation
  - Failure to investigate the obvious
  - Inability to define terms
  - Difficulty in visualizing remote relationships
  - Failure to distinguish between cause and effect
  - Inability to define the problem clearly in terms that will lead to the solution of the real problem

- Cultural blocks[29]
  - Desire to conform to proper patterns, customs, or methods
  - Overemphasis on competition or cooperation
  - The drive to be practical above all else, thus making decisions too quickly
  - Belief that all indulgence in fantasy is a waste of time
  - Faith only in reason and logic

- Emotional blocks
  - Fear of making a mistake or of appearing foolish
  - Fear of supervisors and distrust of colleagues
  - Too much emphasis on succeeding quickly
  - Difficulty in rejecting a workable solution and searching for a better one
  - Difficulty in changing set ideas (no flexibility) and depending entirely upon judicial (biased) opinion
  - Inability to relax and let incubation take place

The following list adapted from Michel Thiry's "good idea killers" could also be used to make the team aware of attitudes to avoid:[30]

- It is not realistic.
- It is technically impossible.
- It does not apply.
- It will never work.
- It does not correspond to standards.
- It is not part of our mandate.
- It would be too difficult to manage.

[29] Political blocks can also be included here.

[30] Michel Thiry, *Value Management Practice* (Newtown Square, PA: Project Management Institute, 1997), 57.

- It would change things too much.
- It will cost too much.
- Management will never agree.
- We do not have time.
- We have always done it that way.
- We already tried it.
- We have never thought of it that way.
- We are already too far into the process.

The Creative Phase does not necessarily identify final solutions or ideas ready for immediate implementation. It often simply provides leads that point to final solutions.

Beginning the Creative Phase with a creativity-stimulating exercise can also be useful. Kaufman and McCuish[31] report a threefold increase in ideas with the use of such a stimulus. For example, they suggest using the Impossible Invention creativity exercise developed in the Massachusetts Institute of Technology (MIT) creativity lab in the 1960s. This 30-minute exercise consists of dividing the participants into three- or four-person teams. Each team then progresses through preliminary steps to select the three worst ways to perform the function without knowing why or the parameters that define worst. The objective of the exercise is for team members—as a team and as individuals—to experience how far beyond the teams' paradigm they can venture in an environment in which their self-esteem is protected.

2. Establish Ground Rules

The ground rules for creative idea generation, as adapted from Parker,[32] are summarized as follows:

- Do not attempt to generate new ideas and judge them at the same time. Reserve all judgment and evaluation until the Evaluation Phase.
- Focus on quantity, not quality. Generate a large quantity of possible solutions. As a goal, multiply the number of ideas produced in the first rush of thinking by 5 or even 10.
- Seek a wide variety of solutions that represent a broad spectrum of attacks upon the problem. The greater number of ideas conceived, the greater likelihood of an alternative that leads to better value.
- Freewheeling is welcome. Deliberately seek unusual ideas.

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[31] J. Jerry Kaufman and James D. McCuish, "Getting Better Solutions with Brainstorming," in *SAVE International 42nd Annual Conference Proceedings* (Denver, CO, May 5–8, 2002).

[32] Donald E. Parker, *Value Engineering Theory*, rev. ed. (Washington, D.C.: The Lawrence D. Miles Value Foundation, 1998), 96.

- Watch for opportunities to combine or expand ideas as they are generated. Include them as new ideas. Do not replace anything.
- Do not discard any ideas, even if they appear to be impractical.
- Do not criticize or ridicule any ideas. (Criticism could be discouraged, for example, by maintaining a criticizer list or imposing a mock penalty on criticizers.)

3. Generate Alternative Ideas

In this phase of the study, generating a free flow of thoughts and ideas for alternative ways to perform the functions—not how to design a product or service—is important. While creativity tools are available for problem-solving situations, no specific combination of techniques is prescribed for all VE efforts, and the degree to which they should be used is not predetermined. The selection of specific techniques and the depth to which they are used are primarily matters of judgment and vary according to the complexity of the subject under review.

The following list of idea-generation techniques describes some commonly used approaches in the VE context:[33]

- **Brainstorming.** Brainstorming is a free-association technique that groups use to solve specific problems by recording spontaneous ideas generated by the group. It is primarily based on the premise that one idea suggests others, and these suggest others, and so forth. An individual can brainstorm, but experience has shown that a group can generate more ideas collectively than the same number of persons thinking individually. Roger B. Sperling has suggested combining group and individual brainstorming.[34] He found that after the group brainstorming process was complete, individual brainstorming can generate additional ideas of comparable quality.
- **Gordon technique.** The Gordon technique is closely related to brainstorming. The principal difference is that no one except the group leader knows the exact nature of the problem under consideration. This difference helps avoid the premature ending of the session or egocentric involvement. A participant may cease to produce additional ideas or devote energy only to defending an idea if he/she is convinced that one of the ideas already proposed is the best solution to the problem. Selecting a topic for such a session is more difficult than selecting a topic for a brainstorming session. The subject must be closely related to the

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[33] Some of the following material was adapted from information in Army Pamphlet 11-3, *Value Engineering* (n.d.), and DoD Handbook 4245.8-H, Value Engineering (March 1986).

[34] Roger B. Sperling, "Enhancing Creativity with Pencil and Paper," in *SAVE International 39th Annual Conference Proceedings* (San Antonio, TX, June 27–30, 1999), 284–289.

problem at hand, but its exact nature must not be revealed until the discussion is concluded.

- **Checklist.** The checklist technique generates ideas by comparing a logical list of categories with the problem or subject under consideration. Checklists range from the specialized to the extremely generalized.
- **Morphological analysis.** Morphological analysis is a structured, comprehensive system for methodically relating problem elements to develop new solutions. In this approach, the problem is defined in terms of its dimensions or parameters, and a model is developed to visualize every possible solution. Problems with too many parameters rapidly become intractable.
- **Attribute listing.** The attribute listing approach lists all of the various characteristics of a subject first and then measures the impact of changes. By so doing, new combinations of characteristics (attributes) that will better fulfill some existing need can be determined.
- **Input-output technique.** The input-output technique establishes output, establishes input as the starting point, and varies combinations of input/output until an optimum mix is achieved.
- **Theory of Inventive Problem Solving (TRIZ).** TRIZ (for the Russian Teoriya Resheniya Izobretatelskikh Zadatch) is a management tool whose use will increase with greater awareness of its capabilities. The methods and tools are embodied in a five-step process: problem documentation and preliminary analysis, problem formulation, prioritization of directions for innovation, development of concepts, and evaluation of results. C. Bernard Dull points out that VE and TRIZ have strengths and weaknesses.[35] Combining these two problem-solving methodologies can create synergies that lead to more robust and comprehensive results, especially for more technically complex projects where the added benefit is worth the effort. He suggests that integrating TRIZ into the VE job plan is easier than integrating VE into the TRIZ job plan. Dana W. Clarke goes into greater detail in the Creative Phase by suggesting how TRIZ can be used to augment traditional brainstorming.[36] Ball supports Clarke's conclusion: "This is a much more intensive method of identifying potential solutions than generally used in a VM [Value Management] study."[37]

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[35] C. Bernard Dull, "Comparing and Combining Value Engineering and TRIZ Techniques," in *SAVE International 39th Annual Conference Proceedings* (San Antonio, TX, June 27–30, 1999), 71–76.

[36] Dana W. Clarke, Sr., "Integrating TRIZ with Value Engineering: Discovering Alternative to Traditional Brainstorming and the Selection and Use of Ideas," in *SAVE International 39th Annual Conference Proceedings* (San Antonio, TX, June 27–30, 1999), 42–51.

[37] Henry A Ball, "Value Methodology – The Link for Modern Management Improvement Tools," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003).

When using any one of these techniques, the team reviews the elements of the problem several times. If possible, new viewpoints should be obtained by discussing the problem with others. Different approaches should be used if one technique proves to be ineffective.[38] However, before rejecting any possible solutions, one effective strategy allows the team to take a break to allow time for subconscious thought on the problem while consciously performing other tasks.

E. Evaluation Phase

The Evaluation Phase selects and refines the best ideas for development into specific value improvement recommendations. Ultimately, the team should present the decision-maker a small number (e.g., fewer than six) of choices. In the Creative Phase, a conscious effort was made to prohibit judgmental thinking because it inhibits the creative process. In the Evaluation Phase, all the alternatives must be critically assessed to identify the best opportunities for value improvement. This phase is not the last chance to defer ideas. A detailed cost-benefit analysis conducted in the Development Phase leads to the final set of choices presented to the decision-maker. The following subsections describe the activities during the Evaluation Phase.

1. Eliminate Low-Potential Ideas

Ideas that are not feasible, too hard, not promising, or do not perform the basic function should be eliminated. A useful approach to this activity is to classify the ideas into three categories:

- **Yes.** These ideas appear to be feasible and have a relatively high probability of success.
- **Maybe.** These ideas have potential but appear to need additional refinement or work before they can become proposals.
- **Not Now.** These ideas have little or no potential at this time.

At this point, eliminate only the "not now" ideas.

2. Group Similar Ideas

The remaining ideas are grouped into several (three or more) subject-related categories and examined to determine if they should be modified or combined with others. Sometimes, the strong parts of two different ideas can be developed into a winning idea. In other cases, several ideas can be so similar that they can be combined into a single all-encompassing idea. Some workshops employ a "forced relationships" technique that

[38] Some work has been done on a systematic approach for moving between creative methodologies. See Donald Hannan, "A Hybrid Approach to Creativity," in *SAVE International 41st Annual Conference Proceedings* (Fort Lauderdale, FL, May 6–9, 2001).

deliberately attempts to combine ideas from the different subject-related categories to discover new, innovative alternatives.

3. Establish Idea Champions

The remaining activities in this phase are designed to prioritize the ideas for further development. An idea champion is a study team member who will serve as an idea's proponent throughout the prioritization process. If an idea has no champion, it should be eliminated at this point.

4. List the Advantages and Disadvantages of Each Idea

The advantages and disadvantages of each idea are identified along with the ease of change, cost, savings potential, time to implement, degree to which all requirements are met, and likelihood of success. All of the effects, repercussions, and consequences that might occur in trying to accomplish a solution should be anticipated.

Useful suggestions include how to overcome the disadvantages. No matter how many advantages an idea has, disadvantages that cannot be overcome may lead to its rejection.

5. Rank the Ideas

A set of evaluation criteria should be developed to judge the ideas, using the factors considered when listing advantages and disadvantages (e.g., cost, technical feasibility, likelihood of approval, time to implement, and potential benefit). The ideas should be ranked according to the criteria that have been developed. No idea should be discarded, and all ideas should be evaluated as objectively as possible. Ratings and their weights are based on the judgment of the people performing the evaluation. Techniques such as evaluation by comparison, numerical evaluation, or team consensus can be used. Simplified decision analysis techniques such as QFD can also be applied. Chang and Liou suggest using a simplified risk identification and analysis process to evaluate the performance of alternatives and combining these results with criteria weights to determine the best alternatives for further development.[39]

This initial analysis will produce a shorter list of alternatives, each of which has met the evaluation standards set by the team. At this point in the Evaluation Phase, adapting an idea suggested by John D. Pucetas for the Creative Phase might be useful. Pucetas recommends using Force Field Analysis, which evaluates helping and hindering forces in the pursuit of a product, to "measure the sensitivity of the VE team regarding

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[39] Yuh-Huei Chang and Ching-Song Liou, "Implementing the Risk Analysis in Evaluation Phase to Increase the Project Value," in *SAVE International 45th Annual Conference Proceedings* (San Diego, CA, June 26–29, 2005).

controversial project issues."[40] For the higher ranked ideas, the VE team should suggest ways to improve upon the disadvantages and enhance the advantages. This exercise can lead to the following potential benefits:

- Ideas can be revised to improve their potential for success.
- Insight into implementation issues can be obtained from the suggested ways to improve the disadvantages.
- Insight into the acceptability of the idea and the likelihood of management approval can be derived from suggested ways to enhance the advantages.

This approach can serve as a basis for distinguishing among the higher ranked ideas (i.e., reranking the ideas) and consequently simplifying and strengthening the process of selecting ideas for further development.

6. Select Ideas for Further Development

Typically, a cutoff point is established for identifying ideas for further development. If a natural break occurs in quantitative evaluation scores, a cutoff point may be obvious. If only qualitative evaluation scores are used or if quantitative scores are close, a more refined ranking scheme may be needed to make the selection. However, if several alternatives are not decisively different at this point, they should be developed further.

Alternatives with the greatest value potential will normally be among those selected. If that is not the case, those ideas should be reexamined to determine whether they should be developed further. Retaining at least one idea from each of the subject-related categories used to group ideas at the beginning of the Evaluation Phase is also useful.

F. Development Phase

The Development Phase determines the "best" alternative(s) for presentation to the decision-maker. In this phase, detailed technical analyses are made for the remaining alternatives. These analyses form the basis for eliminating weaker alternatives. The following subsections describe the activities during the Development Phase.

1. Conduct a Life-Cycle Cost Analysis

A life-cycle cost analysis ranks all remaining alternatives according to an estimate of their life-cycle cost-reduction potential relative to the present method. Cost estimates must be as complete, accurate, and consistent as possible to minimize the possibility of error in assessing the relative economic potential of the alternatives. Specifically, the

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[40] John D. Pucetas, "Keys to Successful VE Implementation," in *SAVE International 38th Annual Conference Proceedings* (Washington, D.C., June 14–17, 1998), 340.

method used to cost the original or present method should also be used to cost the alternatives.

All costs should be identified. For the originating organization, costs may include

- New tools or fixtures,
- Additional materials,
- New assembly instructions,
- Changes to plant layout and assembly methods,
- Revisions to test and/or inspection procedures,
- Retraining assembly, test, or inspection personnel,
- Reworking parts or assemblies to make them compatible with the new design, and
- Tests for feasibility.

Other costs that are not normally incurred by the originating activity but should be considered include

- Technical and economic evaluation of proposals by cognizant personnel;
- Prototypes;
- Testing the proposed change, including laboratory, firing range, and missile-range charges;
- Additional equipment that must be provided;
- If applicable, retrofit kits (used to change design of equipment already in field use);
- Installation and testing of retrofit kits;
- Changes to engineering drawings and manuals;
- Training personnel to operate and maintain the new item;
- Obtaining new and deleting obsolete stock numbers;
- Paperwork associated with adding or subtracting items from the supply system;
- Maintaining new parts inventory in the supply system (warehousing);
- Purging the supply system of parts made obsolete by the change; and
- Changing contract work statements and specifications to permit implementation of the proposal.

Determining the precise cost associate with a proposed change is not always possible. For example, the actual cost of revising, printing, and issuing a page of a maintenance manual is difficult to obtain. Nevertheless, this charge is a recognized item of cost because the manual must be changed if the configuration of the item is changed. One common practice uses a schedule of surcharges to cover areas of cost that defy precise determination. Such a schedule is usually based on the average of data obtained from various sources.

Comparing alternatives using a "constant dollar" analysis instead of a "current dollar" approach is easier. It permits labor and material cost estimates to be based on current operational and maintenance data and eliminates the need to figure out how they would inflate in some future year. The net present worth of each of the alternatives should be calculated but only after management agrees on two factors:

- **The discount rate to be used.** This figure is the difference between the inflation rate assumed and the time value of money (interest rate).
- **The length of the life cycle.** This measurement is the number of years of intended use or operation of the object being studied.

The Office of Management and Budget (OMB) provides annual guidance on appropriate discount rates.[41] Normally, the Department of Defense (DoD) allows a period of 15–20 years as a reasonable life cycle. However, a program or a command may have different guidance for a particular situation.

2. Determine the Most Beneficial Alternatives

Certain key questions should be answered as part of this effort:

- What are the life-cycle savings?
- Do the benefits outweigh the costs?
- What are the major risks?
- How can the risks be mitigated?
- Are any technical issues outstanding?

If more than one alternative offers a significant savings potential, the common practice is to recommend all of them. One becomes the primary recommendation, and the others are alternative recommendations, usually presented in decreasing order of saving potential. Other non-quantified benefits should also be considered.

The VE team should consult personnel who have knowledge about the item's function, operational constraints, and dependability and requirements. Technical problems related to design, implementation, procurement, or operation must also be determined and resolved.

3. Develop Implementation (Action) Plans

The implementation plan for each alternative should include a schedule of the required implementation steps; identify who will execute the plan; specify the resources required, the approval process, the necessary documents, the timing requirements, the coordination required; and so forth. The team must anticipate problems relating to

[41] OMB Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" (Washington, D.C.:1992).

implementation and propose specific solutions to each. Discussions with specialists in relevant areas are particularly helpful in solving such problems.

When needed, testing and evaluation should be planned for and scheduled during the recommended implementation process. Occasionally, concurrent testing of two or more proposals allows a significant reduction in the implementation investment. Also, significant reductions in test cost can often be achieved by scheduling tests into other test programs scheduled within the desirable time frame—especially when items to be tested are a part of a larger system also being tested. However, care must be exercised during combined testing to prevent masking the feasibility of one concept by the failure of another.

G. Presentation Phase

The Presentation Phase obtains a commitment to follow a course of action and initiate an alternative. The VE team makes a presentation to the decision-maker (or study sponsor) at the conclusion of the workshop. This presentation is normally the first step (not the last step) in the approval process. Typically, a decision to implement is not made at the time of the briefing.

Additional steps include

- Answering follow-on questions,
- Collecting additional data,
- Reviewing supporting documentation, and
- Involving other decision-makers.

The sole activity during this phase involves preparing a presentation to encourage commitment. An oral presentation can be the keystone to selling a proposal. It should make an impact and continue the process of winning management and other stakeholder support. This presentation gives the VE team a chance to ensure that its written proposal is correctly understood and that proper communication exists between the parties concerned. The presentation's effectiveness will be enhanced if

- The entire team is present and introduced;
- The presentation lasts no longer than 20 minutes, with time for questions at the end;
- The presentation is illustrated using mockups, models, slides, vu-graphs, or flip charts; and
- The team has prepared sufficient backup material to answer all questions posed during the presentation.

The presentation itself should

- Describe the workshop objectives and scope,
- Identify the team members and recognize their contributions,
- Describe the “before” and “after” conditions for each alternative,
- Present the costs and benefits, advantages and disadvantages, and impact of each alternative,
- Identify strategies to overcome roadblocks,
- Demonstrate the validity of the data sources, and
- Suggest an action plan and implementation schedule.

The most successful strategies to improve the probability of success and reduce the time required for acceptance and implementation of proposals appear to be the following:

- **Consider the reviewer’s needs.** Terminology appropriate to the training and experience of the reviewer should be used. Each proposal is usually directed toward two audiences: (1) the technical authority that requires sufficient technical detail to demonstrate the engineering feasibility of the proposed change and (2) the administrative reviewers for whom the technical details can be summarized but for whom the financial implications (cost and likely benefits) are emphasized. Long-range effects on policies, procurement, and applications are usually more significant to the administrator than to the technical reviewer.
- **Address risk.** Decision-makers are often more interested in the risk involved in making a decision than the benefits or value that might be achieved by the decision. Decision-making risk should not be confused with technical risk. Decision-making risk encompasses the uncertainty and complexity generated from making change. Therefore, the organizational culture and behavior should be considered when characterizing the recommendation.
- **Relate benefits to organizational objectives.** A proposal that represents advancement toward some approved objective is most likely to receive favorable consideration from management. Therefore, the presentation should exploit all of the advantages that a proposal can offer toward fulfilling organizational objectives and goals. When reviewing a proposal, the manager normally seeks either lower total cost of ownership or increased capability at the same or lower cost. The objective may be not only savings, but also the attainment of some other mission-related goal of the manager.
- **Show collateral benefits of the investment.** Often, VE proposals offer greater benefits than the cost improvement specifically identified. Some of the benefits are collateral in nature and can be difficult to quantify. Nevertheless, collateral benefits should be included in the proposal. The likelihood of the proposal’s acceptance is improved when all of its collateral benefits are clearly identified and completely described.

The Presentation Phase should end with a list of actions leading to approval:

- Preparation and submission of a final workshop report with all the necessary supporting documentation
- Briefings to other key stakeholders
- A schedule for a follow-up meeting to approve the proposal

H. Implementation Phase

The purpose of the Implementation Phase is to obtain final approval of the proposal and facilitate its implementation. Throughout this phase, the team should be mindful of factors that contribute to successful change:

> The VE/VA techniques provide an excellent method for planned and managed change. However, even when the job plan is applied well, challenges to the change process occur due to individual differences and human interpretation. At each stage of the change process, a number of varying responses may be expected from individuals involved throughout the organization. These responses range from active support to resistance. One of the approaches that have demonstrably improved the chances for success of the planned change and reduced reactive resistance is to let people in on the action—to participate in the decision-making process.[42]

Fraser notes the five factors David A. Kolb and Richard E. Boyatzis identified as being most related to achieving a goal: awareness, expectation of success, psychological safety, measurability of the change goal, and self-controlled evaluation.[43]

VE is ideally suited to meeting these challenges. The following subsections describe the activities during the Implementation Phase.

1. Prepare a Written Report

The oral presentation of study results is most helpful to the person who is responsible for making the decision; however, it should never replace the written report. A written report normally demands and receives a written reply, whereas an oral report can be forgotten and overlooked after it is presented. In the rush to conclude a project, promote a solution, or avoid the effort of writing a report, many proposals fail to materialize because the oral presentation alone is inadequate. The systematic approach of the VE job plan must be followed to conclusion and should include the meticulous preparation of a written report.

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[42] R. A. Fraser, "The Value Manager as Change Agent or How to be a Good Deviant," in *SAVE International Annual 24th Conference Proceedings* (Sacramento, CA, May 6–9, 1984), 199–203.

[43] David A. Kolb and Richard E. Boyatzis, "Goal Setting and Self-Directed Behavior Change," in *Organizational Psychology: A Book of Readings*, ed. David A. Kolb, Irwin M. Rubin, James M. McIntyre (Englewood Cliffs, NJ: Prentice-Hall, 1979).

Like any other well-prepared report, this final report should

- Satisfy questions the decision-maker is likely to ask,
- Provide assurance that approval would benefit the organization,
- Include sufficient documentation to warrant a favorable decision with reasonable risk factors (both technical and economic), and
- Show how performance is not adversely affected.

Well-prepared teams get a head start on the final report by documenting the progress between phases. For example, before the Development Phase, each surviving idea should be documented in terms of what is proposed, to what extent the idea meets the criteria established in the Orientation Phase, risk, investment cost, expected savings, and so forth.

The final report should be accompanied by a team letter that summarizes the recommendation and action plan and requests action from the sponsor. It should be sent with the report to all stakeholders.

2. Enhance the Probability of Approval

Approval of a proposal involves change to the status quo. Because of this or other pressing priorities, a manager may be slow in making a decision.

The manager who makes an investment in a VE study expects to receive periodic progress reports before a final decision is made. Regular reporting helps ensure top management's awareness, support, and participation in any improvement program. Therefore, the change should be discussed with the decision-makers or their advisors before and after the final report has been submitted. This practice familiarizes key personnel with impending proposals and enables a more rapid evaluation. Early disclosure can also serve to warn the originators of any objections to the proposal. This "early warning" will give the originators an opportunity to incorporate explanations and details into the final report to overcome the objections. These preliminary discussions often produce additional suggestions that improve the proposal and enable the decision-maker to contribute directly.

Implementation depends on the expeditious approval by the decision-makers in each organizational component affected by the proposal. The VE team members should serve as liaisons between decision-makers and other stakeholders by preparing information that weighs the risks against the potential rewards and by identifying potential roadblocks and solutions.

Some organizations convene an implementation meeting with all stakeholders.[44] Once tentative decisions are made, this meeting is used to help everyone understand

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[44] Jill Ann Woller, "Value Analysis: An Effective Tool for Organizational Change," in *SAVE International 45th Annual Conference Proceedings* (San Diego, CA, June 26–29, 2005).

which proposals or modified proposals have been accepted or rejected or will be studied further. In some cases, the tentative decisions are changed based on clarification of a misunderstood assumption.

3. Monitor Progress

Implementation progress must be monitored just as systematically as the VE study. The VE study team should ensure that implementation is actually achieved. A person could be given the responsibility of monitoring the deadline dates in the implementation plan and the process of obtaining any implementation funding.

4. Expedite Implementation

To minimize delays in the implementation process, the VE team should provide assistance, clear up misconceptions, and resolve problems that may develop in the implementation process. When possible, the VE team should prepare first drafts of the documents necessary to revise handbooks, the specifications, the change orders, the drawings, and the contract requirements. Such drafts help to ensure proper translation of the idea into action and serve as a baseline from which to monitor progress of final implementation. The VE team should review all implementation actions to ensure communication channels are open and that approved ideas are not compromised by losing their cost effectiveness or the basis for original selection.

5. Follow-up

The final activity of the Implementation Phase includes several diverse tasks that foster and promote the success of subsequent VE efforts:

- Obtain copies of all complete implementation actions
- Compare actual results with original expectations
- Submit cost savings or other benefit reports to management
- Submit technical cross-feed reports to management
- Conduct a "lessons-learned" analysis of the study to identify problems encountered and recommend corrective action for the next study
- Publicize accomplishments
- Initiate recommendations for potential future VE studies on ideas evolving from the study just completed
- Screen all contributors to the effort for possible receipt of an award and initiate recommendation for appropriate recognition

3. Lean Six Sigma (LSS) Methodology[45]

This chapter describes two methodological approaches to LSS. Some LSS proponents have asserted that no continuous process improvement methodology has "a more balanced approach or success than Lean Six Sigma."[46] In fact, the word "lean," when used as an adjective, often connotes a new and streamlined way of carrying out some activity using lean principles. For example, lean design has been defined as "the power to do less of what doesn't matter and more of what does matter."[47]

The first approach to LSS is the Define, Measure, Analyze, Improve, and Control (DMAIC) methodology. It is by far the most common. The steps in the DMAIC process are described in Section A and diagrammed in Figure 4. The LSS variant Design for Six Sigma (DFSS) methodology is discussed in Section B.

A. The DMAIC Methodology

1. Define Phase

The LSS methodology begins with the Define Phase when a problem area is first recognized and opportunities to reduce waste and/or variation are explored. The objective of the Define Phase is to comprehensively examine a problem area by narrowing down and scoping the areas of deficiency. The Define Phase entails identifying an area for improvement, developing a more detailed understanding of the associated process, identifying project goals, forming a team, developing initial process maps, identifying roadblocks and solutions, and finalizing a problem statement to guide project work.

The process owner plays a vital role in the Define Phase by communicating requirements, goals, and guidance to the team and steering the project and managing the budget. Other major players include the project champion, who serves as a go-between for the team and senior leadership and approves major decisions; an LSS Black Belt and/or LSS Master Black Belt who oversees and manages the project, provides expert guidance, and trains and prepares the team; and the team members. An effective Define Phase will rec-

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[45] The material in this chapter was adapted from the DoD LSS Black Belt Course and the DoD LSS Champion Course as contained in the training page of https://www.us.army.mil/suite/page/596053.

[46] JD Sicilia, "Office of the Secretary of Defense Champion Training."

[47] Bart Huthwaite, *The Lean Design Solution* (Mackinac Island, MI: Institute for Lean Design, 2004).

ognize a problem and work with a team to lay the groundwork for further analysis. The following subsections describe the activities during the Define Phase.

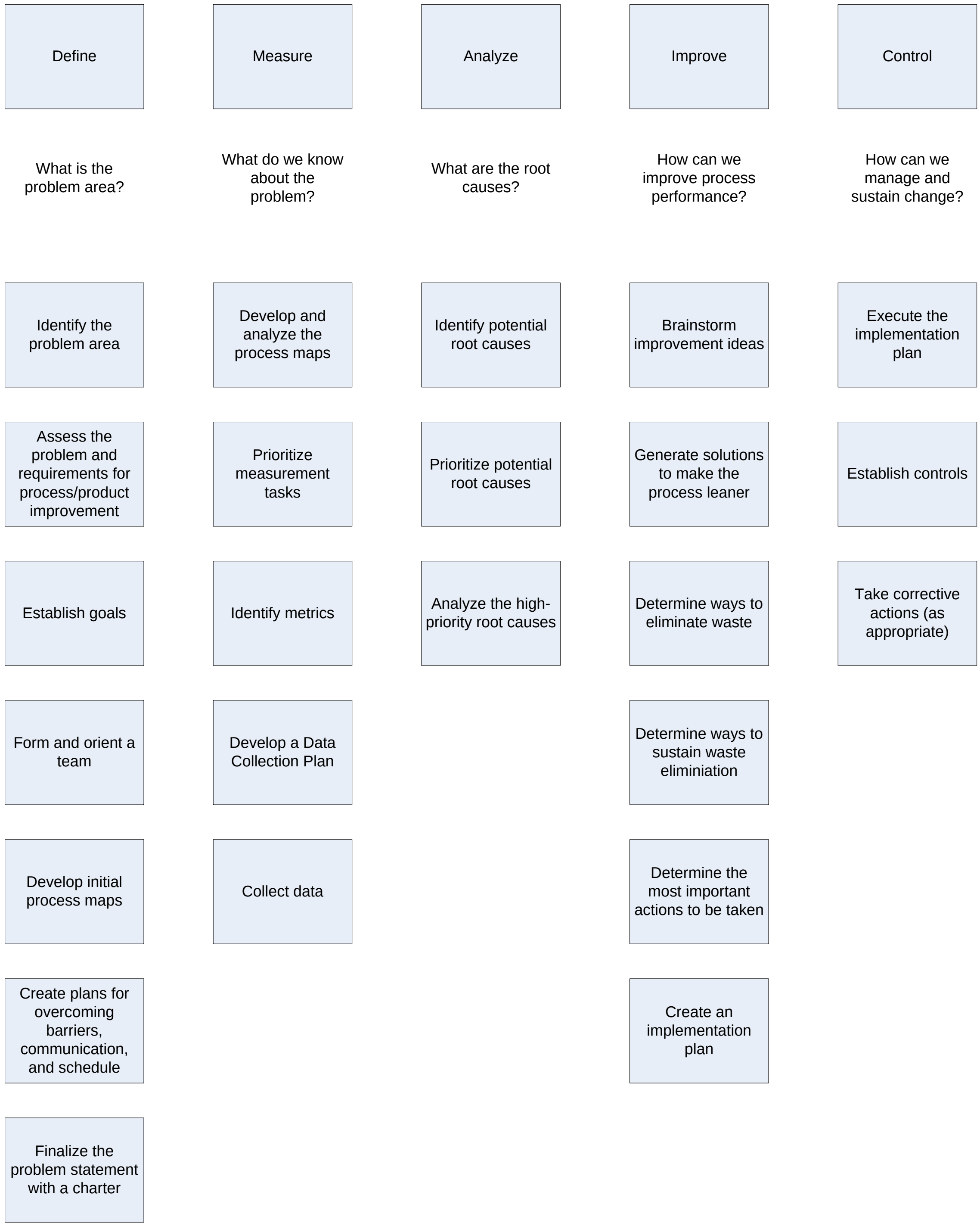

Figure 4. The DMAIC Process

a. Identify the Problem Area

Identifying a problem area is the first step in LSS and process improvement to eliminate waste. This step can entail a broad and brief description of a problem based on observation; however, the problem must be quantifiable. A problem can be identified by anyone at any point in the process, either from a top-down or bottom-up perspective. Problem areas can include cost, productivity, time, defects, safety, or customer satisfaction potential. Corresponding indicators include cost overruns, inefficient use of resources, process overlaps, or an inadequate product.

Sponsor input is crucial in identifying a problem area. This input provides important insights about his/her and the process owner's needs, objectives, or specifics about a process that may not be obvious to an outside observer. A problem does not necessarily need to be identified first by the process owner, but initial findings and recommendations need to be communicated to the champion and customer as part of the identification process.

Part of the identification step is also developing an awareness of the benefits of improving the process by rectifying a problem. Benefit analysis helps by examining parts of the process that relay the greatest value and focusing on those areas that will increase productivity and capture the benefits.

b. Assess the Problem and Requirements for Product/Process Improvement

Once a problem is identified, the next phase is for the champion to work with the process owner and/or sponsor to develop a deeper understanding of the problem and how it fits into a larger process. Assessing the problem area entails moving to an additional level of detail to frame the way ahead and to develop a better understanding of the customer's needs. The assessment should identify what is critical to quality, cost, delivery, safety, customer satisfaction, or any sector within which the problem area falls. Questions for consideration include the following:

- How does the problem impact the entire process?
- Does the entire process have to be changed to address this specific problem?
- What is the most crucial part of the process?
- Can the deficiency be quantified?
- Can the targets be quantified?

This assessment identifies the specific issue for the LSS project and lays the groundwork for moving forward with a plan to improve the process.

The sponsor plays a critical role in this step. He/she provides requirements for process improvement, which must be measurable and relate directly to the product or service. All information about the problem area must be validated with the process owner. The sponsor and the champion will identify important relationships within the organiza-

tion, the process and project's level of importance, and any additional requirements or constraints for the LSS team.

c. Establish Goals

The goal of the previous steps was to identify and focus on a specific problem from which specific goals can be derived with the help of the sponsor. Tools for communicating with the customer include the following:

- **Likert scale.** The Likert scale measures the strength of agreement with a given statement about the process through a questionnaire to gauge attitudes.
- **Surveys.** Surveys provide specific questions to gauge the customer's concerns and requirements. However, participation is often lacking in surveys.
- **Interviews.** Interviews solicit candid feedback, providing the process owner with a direct voice; allow for a free flow exchange of ideas about what is wrong and what can be fixed; and establish face-to-face communication with the sponsor, which may be useful throughout the project.
- **Focus groups.** These groups establish a panel to answer questions about the product or process and solicit feedback directly from those involved in the process.

Project goals should follow the SMART guidelines: Specific, Measurable, Achievable, Relevant, and Time-bound. Once identified, the goals can be prioritized by the sponsor and champion to develop a scope of the problem. The scope must include a beginning, an end, the included/excluded topics, and the level of detail.

Notional metrics are derived from the goals. Any measurable problem should have a metric to gauge LSS progress. Metrics are dependent on the customer and business requirements. Tollgates are a useful tool for establishing and charting metrics. Tollgates include decision points, reviews, or other opportunities to measure efficiency. More efficiency metrics will be identified in the Measure Phase.

d. Form and Orient a Team

The sponsor and the champion have to identify the best candidates for a team. Once the team is selected, it must be introduced to the topic and develop a common understanding of the problem, the project scope, the customer's needs, and the overall process.

The team can then establish ground rules and guidelines in conjunction with a Black Belt and the champion. Rules should ensure that members are open minded, receptive to change, and familiar with the process and subject matter. Tools include a Responsible, Approval, Contributor, and Informed (RACI) chart to establish roles and responsibilities, team-building exercises, and guidance documents (e.g., charter or communications plan).

e. Develop Initial Process Maps

Once the team has become acquainted and shares a common understanding of the problem, its first task is to understand the process as a whole. Process maps are a useful tool in this step. The Supplies, Inputs, Process, Outputs, and Customers (SIPOC) framework provides a guidepost in various steps of LSS. SIPOC is a high-level process map that the team develops to understand and analyze the entire process, including the problem area's scope and impact. Questions during this phase include the following:

- How does this process operate?
- What are the most valuable steps?
- Does the problem area have a significant impact?
- What are the repercussions of addressing/not addressing the problem area within the team's constraints?

The answers to these questions will assist in refining the project and identifying what *will* be covered and what *will not* be covered.

The champion and the sponsor can play a role in this step by providing access to production information and having a first-hand understanding of how the process operates. Other tools for understanding workflow or for use in conjunction with SIPOC include a Pert Chart, which captures workflow and output, and value stream mapping (VSM). A value stream map demonstrates the flow of value-added steps to meet product and/or process requirements.

f. Create Plans for Overcoming Barriers, Communication, and Schedule

A thorough understanding of the process enables the team to identify possible roadblocks and solution sets. Often, the greatest roadblocks are barriers to change within an organization. The team is responsible for recognizing any individual or collective assumptions, preconceived notions about the outcome, or reluctance to press ahead with the LSS project. This risk assessment will include projecting the probability of risk that might affect the project, the customer's willingness to take risks, and how risks can be avoided.

Along with a risk assessment, the team should develop a communications plan. This plan will identify the project's purpose and audience and contain a concise message that captures the specific problem area, requirements, schedule, and deliverables. All these planning tools and documents will need to be validated with the sponsor and vetted with the team.

The team must also establish regular meeting times and locations that are convenient for all members, identify a team leader, and initiate communication with the sponsor and the champion.

g. Finalize the Problem Statement With a Charter

The last step in the Define Phase is refining the problem and finalizing a problem statement. This process is the culmination of the observations, research, and increasing level of detail obtained in the previous steps. A final problem statement will capture how the problem fits into the bigger system. It can be referenced throughout the project to provide direction and ensure the team stays on track. A clear problem statement will guide future work in process improvement and help to orient a team.

The champion plays a crucial role in this phase by ensuring that the problem clearly addresses the objectives. Effective communication will help to avoid misdirection or mistakes throughout the LSS improvement process. An effective problem statement will include quantifiers and a description of the impact on the entire product/process.

When all of the steps have been completed, a charter[48] is finalized to capture the problem statement, describe the problem area, identify the project's scope and the specific defect to be addressed, establish a time line, and officially designate the team. Once the entire team understands and agrees to the information in the charter, it can decide to proceed with collecting information and conducting analysis to improve the process and remedy the problem area.

2. Measure Phase

The Measure Phase of LSS includes the development of a data-collection methodology to capture pertinent aspects of the current processes and their outputs, the collection of the data, and the establishment of a baseline for determining improvement. Measure often includes an analysis of the measurement system and process capability. The SIPOC provides a guidepost in various phases of LSS, starting in the Measure Phase. The Measure Phase is not necessarily time or labor intensive. Before the team starts its research, it should look for "Quick Wins" or solutions that are low risk, readily available, and require minimal analysis. The following subsections describe the activities during the Measure Phase.

a. Develop and Analyze the Process Maps

During the Measure Phase, processes from the Define Phase will be populated with data. Based on findings from the Define Phase, the team will examine the process maps more closely to evaluate the current processes, set data-collection goals, and identify opportunities for improvement based on the data. It will observe and record process steps, including inputs, outputs, reviews, set-up activities, reporting requirements, workplace

[48] Some practitioners refer to this as the statement of work and reserve the term charter for the problem statement from the customer.

skills, operations, and equipment. Based on these observations, it will identify areas for improvement, which should align with the initial findings from the Define Phase.

VSM is the primary tool to identify areas of waste and to ensure that all processes contribute to output and the primary function of the product. Every step must be purposeful and account for what the customer values. VSM identifies places to collect data by breaking down all the steps in the process until waste and variations become evident. Tools including SIPOC, data blocks, and “walking the process” can contribute to the development of a value stream map.

The process maps identify the boundaries of the problem area, as scoped and finalized during the Define Phase. A flowchart or other graphic representation can assist in seeing how the process evolves from conception to development and completion, with consideration for crucial decision points. A high-level process map will consider the role of the customer, supplier, and producer but can also be scoped down to specific processes where a problem may occur, such as shipping or billing. High-level analysis can identify areas of overlap and inefficiency, whereas narrower and detailed maps can signal areas of waste on a smaller scale within one step of the process. Observing the process maps strengthens the team’s understanding of the process and lends credibility and insights to the Measure Phase.

b. Prioritize Measurement Tasks

Prioritization is fundamentally based on two interdependent principles: what is most important to the customer and what has the most significant impact on the process. A more thorough prioritization analysis will be conducted in the Analyze Phase; however, for the Measure Phase, the team must gauge where to focus its data-collection activities, what matters most to the customer, and which steps contribute the highest value to the output. Measuring the process entails observing where the process currently is and identifying the possible ideal state. The latter step requires prioritizing improvement opportunities to direct investments. This process is called “effective utilization.” With the help of the sponsor, the team will be better equipped to understand the process and to identify which tasks are most important for achieving a satisfactory final product.

Prioritization will relate back to the goals established by the customer and team during the Define Phase. Sponsor interviews and further analysis of the value stream map can be implemented to answer the question, “Where is the greatest value?”

c. Identify Metrics

Metrics must be customer focused and capture benefits in the areas of highest value. They must also be specific and quantifiable, leaving no room for errors in judgment. Typical metrics include throughput, inventory, expenses, or any quantifiable steps. One par-

ticularly useful metric is to measure the time required to perform an activity in relation to the time available.

Once the metrics are identified, the team can evaluate and weigh the metrics according to the impact and importance of the aspect of the process being measured. This evaluation will enable the team to determine which data will be the most useful. The team must also identify constraints to the metrics and data points and how they affect collection activities and analysis.

d. Develop a Data-Collection Plan

After identifying metrics, the team must identify data needs and develop a plan to collect the necessary data. Insights from the process maps highlight data-collection techniques and how to capitalize on the available data. Data needs will account for sources of variation and repeatability and reproducibility.

Before the data is collected, the team should stipulate exactly what it is looking for and know where to find the data and how to collect, measure, and apply this data to the analysis. Data-collection plans should follow the SMART metrics. Data must be both qualitative and quantitative. Questions asked during this phase should include the following:

- Where is data available on the high-priority areas?
- How can the data be collected, and is it already captured elsewhere (e.g., an annual report)?
- On what aspects of the process will the team focus?

e. Collect Data

The final step of the Measure Phase is to apply the methodology and go into the field to collect the data. This step requires cooperation and collaboration with the sponsor to gain access to data sources and to establish the integrity of the samples. Initial sampling done earlier in the Define and Measure Phases can provide useful insights into potential challenges and opportunities for the full collection. Once the data is gathered according to the methodology, it is presented to the team for analysis.

3. Analyze Phase

At this point in the DMAIC process, a problem has been defined, and the necessary data has been identified and collected so that the problem can be understood better. The objective of the Analyze Phase is to determine the most critical (high-priority) root causes of the problem being addressed (i.e., sources of variation or deficiency).

The Analyze Phase is designed to identify and understand root causes from multiple perspectives. To minimize the likelihood of overlooking critical information, an effort is

made to identify as many root causes as possible. The most important root causes are determined on the basis of their impact—especially on the customer. A variety of analysis techniques are used on the data associated with these root causes to gain insights into potential corrective actions to mitigate or resolve them. The following subsections describe the activities during the Analyze Phase.

a. Identify Potential Root Causes

The root causes rather than symptoms of the problem should be addressed. A root cause is the underlying reason that a problem occurs. Taking corrective actions on a root cause will prevent the problem from reoccurring. Taking corrective action on a symptom will treat the symptom but not the problem at hand. Also, this effort should not be limited to searching for a single root cause, because an undesirable effect could have multiple root causes. Several techniques can be used to identify potential root causes. Some of the most common are as follows:

- **Brainstorming.** Brainstorming uses open-ended discussion to capture potential drivers causing the problem. The brainstorming process should capture as many ideas as possible. All ideas must be encouraged, and these ideas should not be evaluated or criticized at this time. Weak, impractical, or infeasible ideas will be eliminated later in the process.
- **5 Whys.** Open-ended questions and answers can be informative. Continually asking the questions "why" (as many as five times) helps identify more potential root causes.
- **Fishbone Diagram.** A fishbone diagram organizes the potential root causes into categories. A relationship exists between these categories and the brainstorming process. After all brainstorming ideas are collected, developing an affinity diagram will help in defining the major fishbone categories. Using the 5 Whys can break down the categories (or elements within a category) into smaller components. These categories and the smaller components may represent inputs to the overall process, or they may be found on the process maps.

b. Prioritize Potential Root Causes

Common prioritization techniques can be focused strictly on the root causes already identified. They can also be used to supplement the identification effort by looking at a more expansive situation, not just the specific problem at hand. Prioritization is fundamentally based on two interdependent principles: what is most important to the customer and what has the most significant impact on the process. Common prioritization techniques are as follows:

- **Voting.** Simple voting is a first-cut prioritization method and can use a high-, medium-, and low-importance scale.

- **Pareto charts.** Pareto charts show the relative frequency of the factors (potential root causes) that contribute to the problem. Many times, only a few factors will account for a bulk of the problems.
- **XY matrix:** In an XY matrix, the Xs represent the potential root causes and are usually taken from a fishbone diagram. The Ys are the outputs of the process that are important to the customer, and these may be more encompassing than the immediate problem at hand. Stakeholders are asked to numerically rate the effect of each X on each Y and the relative importance of each of the Ys. In that way, using quality function deployment techniques, the Xs can be prioritized.
- **Failure Modes and Effects Analysis (FMEA).** A FMEA is a disciplined procedure that identifies ways in which a process or a product can fail (failure modes) to meet customer requirements, the reasons why the failure occurred (root causes), and the impact of the failure (failure effects). A FMEA can be conducted on just the steps that affect the problem at hand, the steps in the process encompassing the highest priority Xs, every step in the process, or anywhere in between. When used for a product, FMEAs can be employed at the system or subsystem level in the early design stage so the design can address the failure modes observed. FMEAs can also be used to analyze new process designs or to improve operational processes. Prioritization is accomplished by considering the degree of severity of the failure, the likelihood of occurrence (taking into consideration the current controls in effect), and the ability to detect the failure mode.

c. Analyze the High-Priority Root Causes

The high-priority root causes are analyzed to obtain greater insight on what to do about them. This analysis lays the groundwork for determining how to improve the situation in the next DMAIC phase. Root cause analysis techniques vary as a function of the level of knowledge of the situation and the availability of data to support that knowledge. The techniques can be simple or complex. At a basic level, a statistical analysis of the overall process or a part of the process can show the relative magnitude of the problem and provide a measure of process performance over time. More complex statistical analyses can be used to understand variations in much greater depth and to predict the outcome of changes. Some common analysis tools used to establish cause-and-effect relationships between the Xs and Ys include the following:

- **Run charts.** Run charts plot the cycle time of different observations. Outliers can then be examined to determine what they have in common.
- **Graphical analysis.** Graphical analysis is used to understand the distribution of the data so that more sophisticated statistical techniques can be applied.

- **Goodness-of-fit tests.** Goodness-of-fit statistics are used to determine how well the data can be characterized by a specific probability distribution.
- **Hypothesis testing.** Hypothesis tests are statistical techniques for comparing properties or determining whether relationships exist among different populations of data.
- **Scatter diagrams.** Scatter diagrams can assist in confirming relationships among causes and effects. They graphically depict something that can be tested by simple linear regression.
- **Regression testing.** Regression tests quantify the relationship (correlation) between input (independent) and output (dependent) variables. Correlations can also be developed among root causes. Correlation however, does not determine causation.
- **Analysis of Variance (ANOVA).** ANOVA gives a statistical test of whether the means of several groups are all equal so that the effects of various treatments can be compared.
- **QFD.** In building the XY matrix, relationships were developed between root causes and the characteristics important to the customer. QFD extends that concept by examining how specific features, attributes, and/or metrics contribute to what the customer wants. QFD also includes the determination of targets for customer needs and the features, attributes, and/or metrics.

4. Improve Phase

The objective of the Improve Phase is to determine the actions necessary to change the process and improve performance. Improvements occur through increasing value to the customer and eliminating waste. Improvements are quantified by comparisons to the product-/process-related baselines established in the Measure Phase.

Developing potential solutions involves a complex set of activities that should be tailored to the specific situation being addressed. Multiple solution-generation techniques are often employed since different approaches can generate more effective ideas. For example, brainstorming for solutions to the various root causes and the application of lean principles to identify and eliminate waste are complementary approaches. If brainstorming is used to identify mitigation actions for the root causes, the entire new process could then be made lean and safeguarded to eliminate mistakes and avoid “back sliding.” The Improve Phase ends with determining the most effective mitigation actions and developing a plan to implement them. The following subsections describe the activities during the Improve Phase.

a. Brainstorm Improvement Ideas

Solutions should be generated for all of the high-priority root causes in the XY matrix, one at a time. As many solutions as possible should be generated since the best ideas will be determined later. Team-based brainstorming is a structured and effective way of generating many ideas in a short period of time. The key to successful brainstorming is to keep the creative process going by not putting any limits on the ideas suggested and not evaluating ideas during the brainstorming process.

The team must overcome conventional assumptions and self-imposed constraints. One useful exercise is to "tear apart" the existing process and challenge everything that it does. "We've always done it this way" is not a reason to continue the same practices in the future. Once some team members suggest new ways of doing things, others become inspired to build on these new ideas.

Brainstorming is typically carried out in a "round-robin" fashion. When the flow of new ideas slows, the team should begin the process again. When these iterations have finally ended, the team should review all ideas to ensure that everyone has a common understanding of their meaning.

Completion of the review should be followed by an initial screening of ideas. Some ideas may violate a law or be too risky. All impractical or infeasible ideas should be eliminated at this point. All remaining ideas will imply changes to the process and will form a set of potential to-be processes.

b. Generate Solutions To Make the Process Leaner

Some basic lean principles are as follows:

- Specify what creates value from the customer's perspective
- Identify the steps in the process chain
- Implement changes needed to improve process flow
- Produce only those things that are demanded by the customer
- Continuously remove waste from the processes

Waste must be identified before it can be eliminated. The seven areas of waste are

- Rework/correction,
- Over production,
- Unnecessary processing,
- Excess conveyance/transportation and inventory,
- Unnecessary movement,
- Waiting, and
- Unnecessary investment.

Process variation clearly results in waste. The root causes of process variation determined in the Analyze Phase represent sources of waste. Therefore, to identify waste, special attention should be paid to those steps in the process associated with the root causes.

Waste can often be identified by examining the overall process as it works today and as it might work in the future given the implementation of some of the ideas developed during the brainstorming process. Determining the time required for each step in the process and then identifying the value added by that step provide an opportunity to identify waste. If a bottleneck in a process takes time but does not add any value to the customer (and is not a mandated requirement), it is waste. Waste is identified throughout the entire process, not just the areas where root causes of variation were found.

These efforts, when completed, accomplish two important objectives:

- Identify potential waste associated with the changes proposed to fix the high-priority root causes.
- Identify waste in other steps in the process. While these areas of waste may not be associated with the problem at hand, they undoubtedly add cost to the process and may represent some "low-hanging fruit" in terms of improvement to the process.

c. Determine Ways To Eliminate Waste

All waste should be eliminated; however, the elimination process depends on the situation and is not always obvious. For example, if the process owner is involved, some step in the process can be taken away without any additional effort (e.g., transportation waste can be eliminated by moving things close together). On the other hand, taking a step away can create transition issues that result in other changes when the elimination occurs. For example, excess inventory levels can only be eliminated by changing many elements of a process.

The FMEA begun in the Analyze Phase contributes to waste elimination. The initial FMEA identified the failure mode, failure effect, and cause of failure. All failures represent defects or waste. By identifying the controls needed to eliminate the cause of failure, recommended actions can be developed to mitigate the defect. If new processes are being created, augmenting the initial FMEA may be necessary since any process change may result in unintended consequences.

Another useful waste elimination technique is TOC. A constraint is anything that impedes throughput. The binding constraint in a process is the step that wastes the most time. TOC seeks ways to mitigate this situation so that some other step in the process becomes the binding constraint.

Other common waste elimination strategies include the following:

- **JIT.** Inputs to each step in the process arrive only when needed and in the correct quantity to reduce inventory holding costs.
- **Pull production systems:** Such systems are essential in a JIT environment. The supply of the input to any step in the process is triggered by a signal. Purchase pull systems and replenishment pull systems reduce waiting time.
- **Parallel processing.** This strategy allows independent steps in the process to proceed simultaneously, not serially.
- **Process balancing.** This strategy attempts to ensure optimal use of people, floor space, capital assets, and material. In a parallel processing environment, process balancing will equalize the time needed to accomplish parallel tasks (although the total effort may be different).
- **Process flow improvement.** This strategy reduces time needed to complete a step in the process through simplification accomplished by an improved layout and/or standardized operating procedures.

In some situations, the process of eliminating waste may not be clear. Using a design of experiments (DOE) is a way to better understand the real world. Under DOE, deliberate and systematic changes of input variables are made to observe the corresponding changes in output variables. This approach is often a cost-effective method of determining whether specific actions will work as expected before they are actually implemented.

d. Determine Ways To Sustain Waste Elimination

Application of the 5S standards is one way of making gains sustainable. 5S is a process for creating and maintaining an organized workplace. The 5Ss are

- **Sort** through and remove clutter and unneeded items,
- **Set** the workplace in order and make it obvious where things belong,
- **Shine** the workplace from top to bottom while identifying hazards and mechanical problems,
- **Standardize** guidelines for the 5S conditions, and
- **Sustain** the gains by making an organized workplace part of the culture and the daily routine.

The visual workplace is a process management technique that complements the 5Ss. Visual controls communicate necessary information clearly and quickly. They highlight exactly what is and what is not efficient or effective. In that way, corrections can be targeted to the specific problem.

Standardizing work and mistake-proofing are other ways to sustain the improvements. Mistakes add cost and provide no value to the customer. Mistake-proofing

involves using wisdom and ingenuity to create devices that allow the job to be done 100% defect/error free 100% of the time. The devices can be designed for prevention, detection, warning, or self-correcting control and can simplify the job requirements. For example, something can be made tamper proof if that is a problem that needs to be corrected.

e. Determine the Most Important Actions To Be Taken

In most circumstances, trying to accomplish everything at once is too difficult. Therefore, payoffs from the potential actions should be explored so that the best set of recommended activities can be pursued in the right order. Different ranking tools can be used to help prioritize these activities. For example, a benefit-effort matrix can be created, and emphasis can be placed on low-effort actions, especially those with a high payoff. Ranking criteria can also be developed, and each action can be evaluated to determine those with the highest priority. The team should not lose sight of the most important root causes identified in the Analyze Phase, because addressing these issues will often provide the most effective near-term course of action.

Another important consideration is complexity. Even when a customer considers complexity to be value added, actions that increase complexity should be carefully reviewed before they are incorporated into an implementation plan. Complexity drives costs and increases the potential for error. In some cases, the elimination of complexity is the most cost-effective approach.

Determining the most important actions to be taken always involves unknowns. Solutions may not work as expected. A pilot program can be a valuable step for testing solutions on a small scale before the entire process is affected. It provides an opportunity to discover and mitigate problems earlier in the process. It also provides an opportunity to increase buy-in on the final solution.

f. Create an Implementation Plan

Changes cannot be made until a plan is devised to execute them. The implementation plan includes what needs to be accomplished and the actions needed to do it. Large tasks should be divided into subtasks to make them more manageable. The plan should detail the time and resources required to do the job, the expected start and completion times for the key actions, and the people, equipment, supplies, and money needed to accomplish each action.

An effective implementation plan also describes the roles of all of the key stakeholders involved. Stakeholders include the people who

- Are responsible for making the change,
- Contribute to the nature of the change,

- Must be kept informed of the change, and
- Approve the change.

Implementation plans should address the effects of making the change. For example, when a process becomes more efficient, fewer people will be needed. The implementation plan should show how people will be redeployed into other productive work.

5. Control Phase

The objective of the Control Phase is to ensure that the implementation plan developed in the Improve Phase achieves the desired effect. This objective is achieved by establishing controls to help manage changes. Controls include training, communication, and an implementation monitoring effort. Since few plans are executed as expected, the final part of the Control Phase is a corrective action process.

Another element of the Control Phase, not discussed below, includes LSS project wrap-up efforts. The results of the work should be publicized, and team members should be recognized for their contributions. Opportunities to deploy similar changes elsewhere in the organization should be sought. Finally, lessons learned should be systematically captured. The following subsections describe the activities during the Control Phase.

a. Execute the Implementation Plan

The first step in the Control Phase is to execute the implementation plan created in the Improve Phase.[49] No matter how much effort goes into preparing an implementation plan, its execution rarely proceeds as expected—even when a pilot implementation is used.

Changing the status quo always generates opposition. Cultural adjustments and training are necessary. In some cases, the implemented changes do not produce the predicted effect. Consequently, the implementation effort must be controlled. Without this monitoring, sustaining the gains may not be possible.

b. Establish Controls

Implementation control is accomplished with a control plan. A control plan identifies the actions that are required at each phase of the process to ensure that all process outputs will be in a state of control. It tracks all of the inputs to each phase of the process, describes how the inputs and outputs are being measured, monitored, and controlled, and states what should be done when something is not in control.

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[49] Some LSS practitioners execute the implementation plan in the Improve Phase.

Planned periodic status reviews should be conducted to monitor implementation progress. The control plan identifies metrics that measure the extent to which the implementation plan is being executed as designed, is having an impact at a subprocess level (e.g., errors are being reduced), and is providing the customer with greater value (i.e., the overall process has been improved). The execution-related metrics are often process related and refer to inputs more than to outputs. At the subprocess level, the metrics become output related, and, when dealing with the customer, the metrics usually represent outcomes. Since the old measurement system may not be adequate for the new process in some instances, the measurement system should be evaluated to determine whether it meets the new requirements.

The control plan also identifies the data that should be collected or audits that should be conducted to obtain the desired progress measurements. The auditors should be unbiased and qualified, and the data collected should be measured against a defined standard.

Another key aspect of the control plan is change management. Change takes time and always causes resistance. A control plan attempts to reduce that resistance by ensuring that everyone is informed about the changes and trained to effect the changes. Beyond conventional delivery mechanisms, coaching and on-the-job training are also effective and should not be overlooked. New work instructions, policies, and standard operating procedures must be clear, in place, and communicated thoroughly to all of the stakeholders.

c. Take Corrective Actions (as Appropriate)

The established controls form a feedback system to report deviations in actual outputs from desired levels. Actions need to be taken when the implementation plan is not producing the predicted effect. These actions must be timely and effective and should prevent the recurrence of the problem. The underlying cause of the problem must be identified, and the FMEA may have to be revisited.

A corrective action plan documents the specific actions that need to be taken. Just like the implementation plan, it plan must identify the required steps and resources, the time line, and the roles of all of the key stakeholders. The specific actions should be determined in accordance with a corrective action process that establishes what actions are needed as a function of what problems are encountered. For example, implementation may be too slow, it may not have fixed the problem, or it may have attacked the wrong problem. The corrective action process also tracks who is responsible and whether the corrective actions have been successfully accomplished.

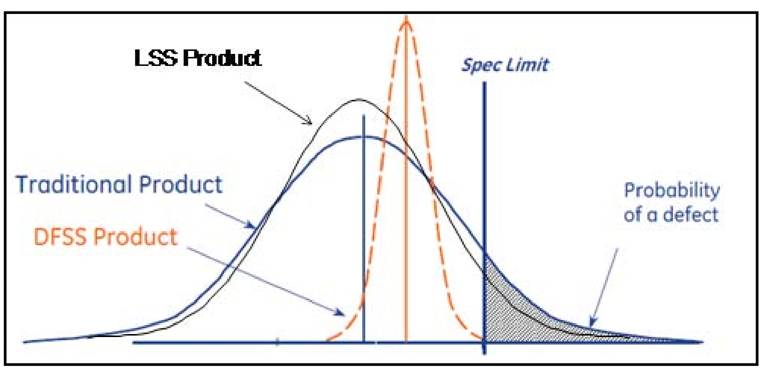
B. The Design for Six Sigma (DFSS) Methodology

1. The Relationship Between DFSS and LSS[50]

DFSS is an approach for applying the LSS thought processes (especially the Six Sigma aspects) to the design of *new* products and processes. LSS and its five-phase DMAIC methodology are not strongly focused on design but on adding value for the customer and supplier and reducing waste/variation in existing products and processes. Six Sigma's origins are derived from the manufacturing floor and, consequently, it is commonly used at the operational stage in the product/process life cycle. At this point in the life cycle, defects (variations) are typically easy to identify but costly to fix.

Preventing defects during the initial design phase produces far greater leverage. At this stage, defects are relatively easy to fix but are more difficult to observe or predict because the design elements have not been finalized. Once the design is complete, most of the costs are locked in. Therefore, the greater the effort in preventing defects (variability) during design, the larger the payoff that can be realized later. The problem with using LSS is that it would attempt to improve something that does not exist—which is why DFSS was created. It adapts LSS to this new product/process situation.

Applying LSS on an existing product/process reduces variability to fewer than 3.4 defects per million units (the Six Sigma level of performance). Figure 5 depicts the application of LSS in reducing variation. The curve labeled "Traditional Product" is meant to depict a situation for a typical defense product. The x-axis represents the performance of some important critical to quality (CTQ) attribute of the system. As far as the customer is concerned, the mean should be as high as possible, as long as the number of defects (indicated by the shaded area) is not too large.



Source: The GE Company

Figure 5. Customer CTQ Attribute

[50] The material in this section was developed from Gene Wiggs. "Design for Six Sigma Introduction," a General Electric (GE) Aviation briefing (September 2005) and Martha Gardner and Gene Wiggs, "Design for Six Sigma: The First 10 Years," vol. 5, *Proceedings of GT2007 ASME Turbo Expo 2007: Power for Land, Sea, and Air* (Montreal, Canada, May 14–17, 2007).

The application of LSS principles would improve the process and reduce the defect rate. In Figure 5, the mean performance value would be the same as the "Traditional Product" curve; however, the distribution would be tighter in a way that experience has shown would reduce the number of defects by about one third.

As shown in the curve labeled "DFSS Product" in Figure 5, the use of DFSS principles will tighten the variability about the mean even further by quantifying the risk and enabling variation levels to be much smaller than with other design philosophies. This enhanced reduction in variation implies much less than 3.4 defects per million units (i.e., a seven, eight, or nine sigma level of performance). Furthermore, it allows the possibility of a specification change by improving the mean performance while maintaining a six sigma (or some other acceptable risk) level of defects.[51]

Such a specification change provides significant potential for performance improvements, competitive advantage, and cost savings. For example, suppose a design change that significantly reduces vibration can be made to an aircraft. This change enables the aircraft manufacturer to reduce insulation and thereby reduce weight. The aircraft manufacturer could then change the vibration specification on the engine because of the improved performance, using DFSS to give a significant advantage to the engine manufacturer.

DFSS can therefore be defined as a systematic methodology for (1) using tools (e.g., QFD, reliability modeling, scorecards, design and analysis of computer experiments, Monte Carlo simulation, accelerated life tests, FMEAs, optimization), (2) training on the steps in the process and the use of the tools, and (3) employing conventional six sigma measurement system analysis to develop products or processes that meet CTQ customer expectations by managing variation in design. To achieve desired performance over time, DFSS matches designs with the manufacturing capabilities (design for producibility), the operating environment (design for reliability and robust design), and the costs (design for affordability). It enables the design to be manufactured so that all customer and regulatory technical requirements are met with minimal defects.

2. How DFSS Affects the Design Process

Instead of DMAIC, DFSS uses the following five-phase process—Define, Measure, Analyze, Design (and Optimize), and Verify (DMADV)—to design quality in rather than to test quality in. [52]

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[51] Figure 5 is drawn to illustrate a point. Technically, the height of the DFSS curve should be far greater so that the area under the DFSS curve is the same as the area under each of the other two curves.

[52] This approach to DFSS is not universally accepted. Different companies have different implementations. The names are different. The acronyms are different. The number of steps is different. However, the activities are similar. See, for example, Lisa A. Reagan and Mark J. Kiemele, *Design for Six Sigma –*

The Define Phase establishes the requirements. The CTQ customer expectations flow down to subsystems and components, and quality goals are set. One type of quality goal is the probability of a defect. This goal is closely related to reliability; however, defects can also result from mistakes in the field and/or errors in the design. The other type of quality goal is more operationally oriented. It deals with the probability of meeting mission performance needs and therefore is an indication of robustness.

The measurement systems are determined in the Measure Phase. These systems are used to collect and understand data on the actual production variation of CTQ elements of existing products/processes overall (e.g., weight) and on the actual producibility, reliability, and cost of their individual parts to create a baseline. The variation change and specification shift depicted in Figure 5 would result from design changes made on the existing products/processes to create the new products/processes or the use of completely new technologies. In the latter case, baseline levels would not be available.

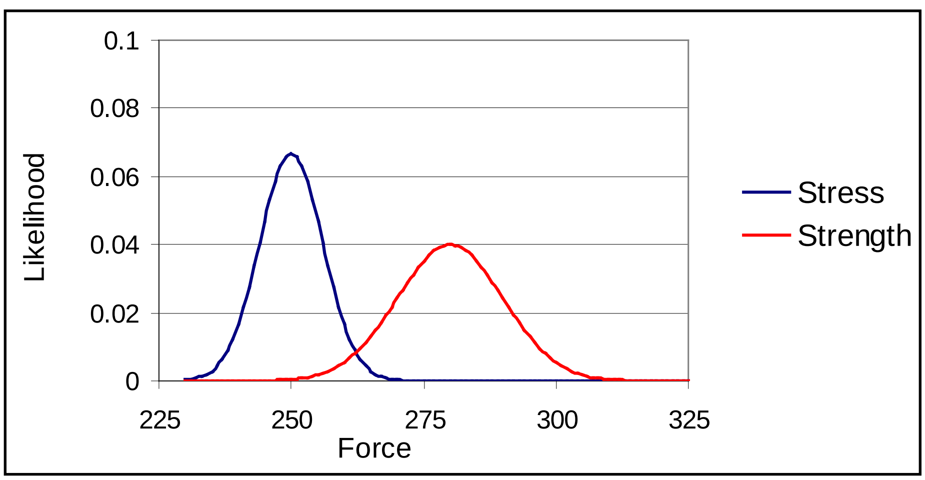
Conceptual designs are developed in the Analyze Phase. These conceptual designs enable architectural decisions. An architectural decision involves something that affects several CTQs simultaneously. For example, in the design of a new car, determining whether that car will have a six-cylinder engine option or a four-cylinder engine option is an example of an architectural decision based on conceptual design. If a four-cylinder engine could satisfy all customer expectations for acceleration and performance, several additional CTQ customer requirements (e.g., fuel economy, vibration, noise, space, weight, crash protection, and fuel-based emissions) are affected.

Also, the framework for making risk assessments is established in the Analyze Phase. Unlike DMAIC, which is concerned with statistics (what is actually happening), DMADV deals with probabilities (what may occur). These probabilities can be derived from computer simulations based on system physics or from estimates based on historical data. Consequently, risks associated with quality goals can be quantified on quality scorecards for CTQ requirements at the system level and for cost, reliability, and producibility at the part level. These scorecards show target values, expected values, standard deviations, and defects per million units. This defect rate is used to make quantitative, risk-based design trades. It quantifies how much risk is acceptable and therefore drives design decisions.

The Tool Guide for Practitioners (Bainbridge Island, WA: CTQ Media, 2008). This book uses identify, design, optimize, and verify (IDOV) as its framework. The implications for synergies with VE are the same. Because of the absence of a standardized approach to DFSS, a description of the steps analogous to what was done for the job plan or DMAIC has not been constructed. A reference for the DMADV approach is Eric Maass and Patricia D. McNair, *Applying Design for Six Sigma to Software and Hardware Systems* (Upper Saddle River, NJ: Prentice Hall, 2009).

System and component models (both physical simulations such as designed experiments and physics-based models) are constructed in the Design (and Optimize) Phase. These models are used to predict the expected performance of CTQ requirements at the system level and reliability and producibility at the part level. The models are used to evaluate how the variation of potential new part designs will differ from the baseline data collected in the Measure Phase. The use of mathematical transfer functions enables an estimation of how predicted changes in mean and variance at the part level will affect the variation of CTQ attributes for the system. With an understanding of the process capability of the production line, a determination is made of whether designs with sufficiently small variation are producible. These model-developed expected values and variation are used to complete the scorecards and calculate expected defects per million to determine the acceptability of the risk. Consequently, critical design parameters can be controlled analytically so that fewer prototypes have to be built and tested even though building prototypes to verify key theoretical findings from the models is common. In addition, design revisions are minimized. This approach is the beginning of design for producibility and affordability.

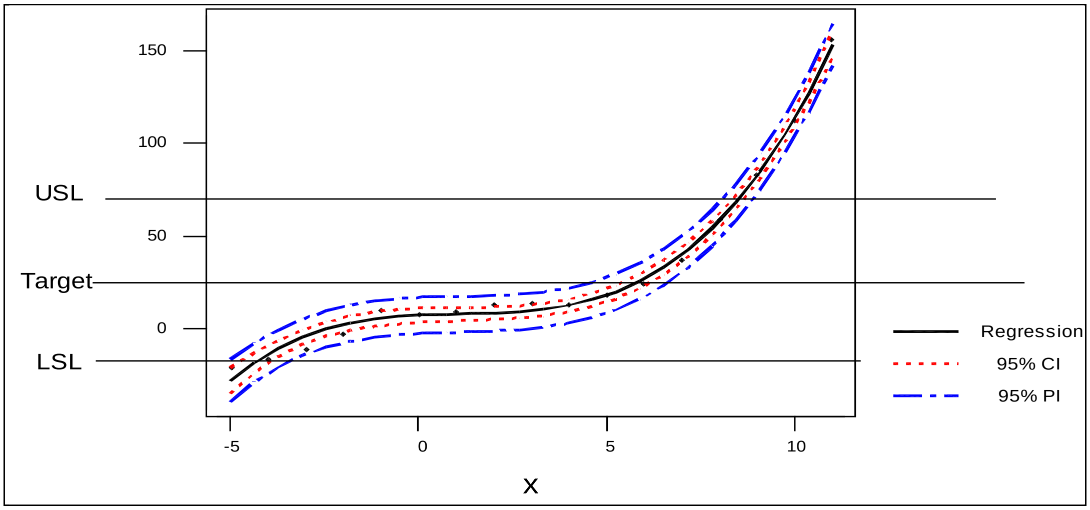
The optimization element in the Design (and Optimize) Phase focuses on reliability, robustness, and tolerance. The goal is to optimize a detailed design that minimizes cost by creating robust, producible designs that are tolerant of variation at acceptable risk levels associated with reliability and performance. Figure 6 illustrates design for reliability. It shows the probability distributions of the force that the part can withstand (strength) and the force that the part may be subject to (stress). The overlap of the stress (that may be encountered in the field) and strength (the design characteristic of a part) curves indicates places where a part can fail. Designs mitigate this by moving the stress curve to the left or the strength curve to the right.



Source: The GE Company

Figure 6. Stress and Strength in Design

Figure 7 illustrates an application of robust design and shows that the importance of determining how much the design has to back off from the deterministic optimum to account for variation in the independent variable. In the figure, the optimum value of X, the independent variable representing something that might happen in the field, is where the regression curve achieves the target Y value for some CTQ attribute, or approximately X = 6. However, X is subject to variation with a standard deviation of 2. Therefore, a value of X three standard deviations above 6 would produce a Y value above the upper limit. For an X of approximately 2, three standard deviations in either direction yield a Y value between the bounds.



Source: The GE Company

Figure 7. Application of Robust Design

The modeling, design development, scorecard completion, risk evaluation, and design optimization discussed previously are performed iteratively in this phase. These steps are performed for system architectures in conceptual designs, for second-order architectural configurations in preliminary design, and for design-to-print package development in detailed design.

In the Verify Phase, design verification using pilot, pre-production, and production units ensures that all requirements are met. DMAIC-like control plans are developed and then the transition to production occurs.

3. Complexity

Complexity, as measured by the number and difficulty of critical elements or actions involved, influences the likelihood of defects resulting from both variation and mistakes.[53] Therefore, effective design encompasses more than the control of variation.

[53] See C. Martin Hinckley, *Make No Mistake* (New York, NY: Productivity Press, 2001).

Many failures in the field are associated with errors. These errors can be mistakes by the user (e.g., inadequate human factors engineering), by the maintainer (e.g., wrong part replaced because several parts look similar), by the manufacturer (e.g., the product was assembled incorrectly because of apparent symmetries), or by the design team.

For example, consider a design that requires 80 holes to be drilled to fasten two parts together. Serious consequences can occur if only 79 holes are drilled. The fact that the wrong number of holes was drilled is a process control problem, *not* a statistical variation problem. Another example would be two similar parts that an assembler could confuse and put in the wrong place. A well-thought-out design for manufacturing and assembly, coupled with a set of best process control practices, should prevent many of these mistakes.

The risk associated with these errors cannot be quantified by the physics-based modeling approach described previously or by process variation distributions. A FMEA can be created in the Analyze Phase and used in the Design Phase to identify the risks and the measures taken to mitigate them. For example, design processes can be error proofed to some extent by incorporating automation, checklists, and non-advocate reviews. The team should work in the Design Phase to reduce complexity by using standard processes and standard parts and features and by decreasing the sheer number of parts.

4. Comparison of VE and LSS Methodologies

A. VE and LSS Cross-Reference

Figure 8 overlays the VE and LSS activities portrayed in Figure 1 and Figure 4. The steps in our discussion of VE and LSS represent a synthesis of information from literature and training material to provide the reader an appreciation for the logical flow of events that transition smoothly from one activity to another, working toward a solution.

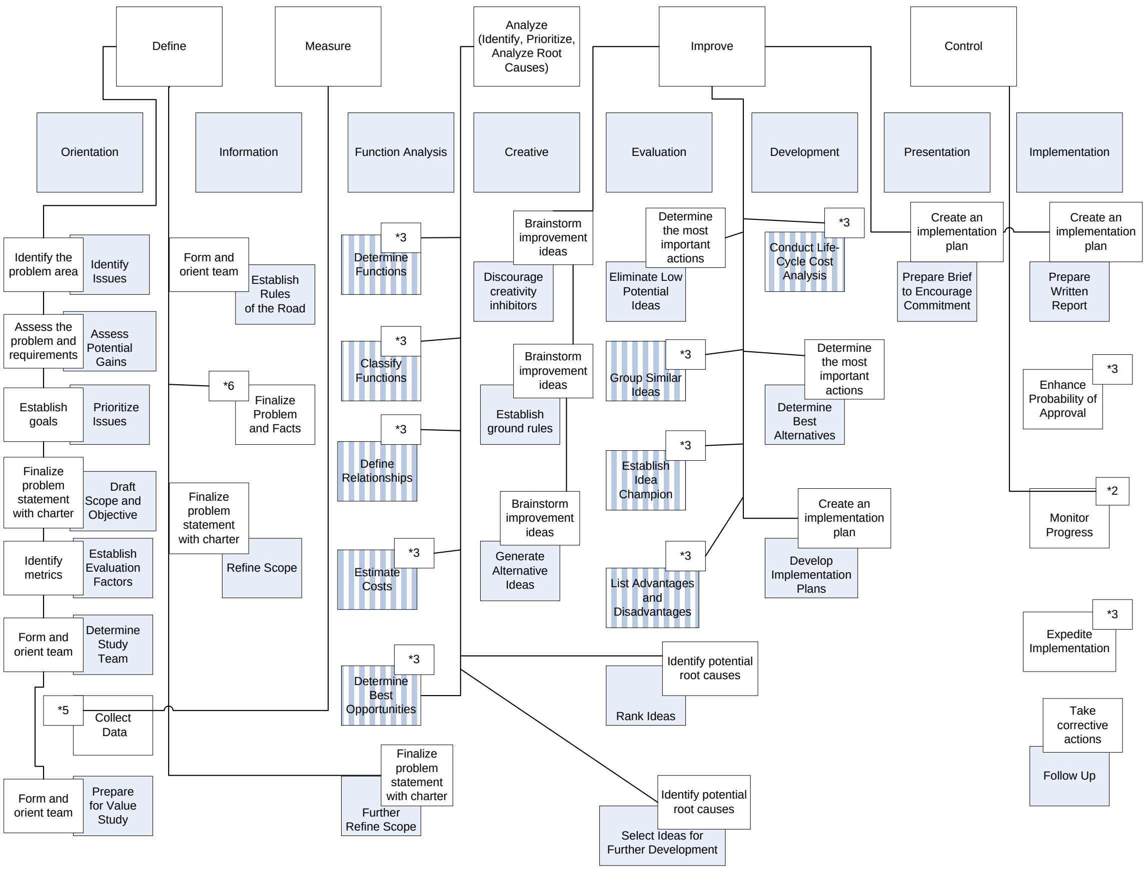


Figure 8. VE Job Plan Cross-Referenced With DMAIC Methodology

Figure 8 identifies correlations, similarities, differences, and opportunities for synergies between the two methodologies. Gray boxes represent the VE job plan, and white boxes represent the DMAIC methodology. In some places, a one-to-one correlation exists. For example, the single step in the VE Orientation Phase to "Establish Evaluation Factors" that matches "Identify Metrics" in the DMAIC Measure Phase. In other places,

the mapping is more complex. Cases where multiple DMAIC activities map into a single VE job plan activity are striped. The activities represented by diagonal stripes identify structural differences (in the Define, Measure, and Control Phases), and the activities represented by vertical stripes represent a difference in the analytical approach (in the Analyze and Improve Phases). The corresponding number beside these boxes identifies the number of overlapping DMAIC activities. These areas represent the highest potential for synergy. As an example of how to navigate this chart, consider the “Determine Functions” activity in the Function Analysis Phase of the VE job plan. This activity corresponds to a DMAIC box with *3, and is linked to the Analyze Phase. This means that the “Determine Functions” activity correlates to three activities in the Analyze Phase of the DMAIC methodology. Table 1 shows breakdown of these numbered boxes. Appendix A contains more detailed cross-reference charts.

Table 1. Figure 8 Notes

Structural (Define, Measure, and Control Phases)
Collect Data (5): Develop initial process maps, develop and analyze the process maps, prioritize measurement tasks, develop a data-collection plan, collect data
Finalize Problem and Facts (6): Develop initial process maps, develop and analyze the process maps, prioritize measurement tasks, develop a data-collection plan, collect data, finalize problem statement with a charter
Enhance Probability of Approval (3): Create plans for overcoming barriers, communication, and schedule; execute the implementation plan; establish controls
Monitor Progress (2): Execute implementation plan, establish controls
Expedite Implementation (3): Execute the implementation plan, establish controls, take corrective actions (as appropriate)
Analytical (Analyze and Improve Phases)
Determine Functions (3): Identify potential root causes, prioritize potential root causes, analyze the high-priority root causes
Classify Function (3): Identify potential root causes, prioritize potential root causes, analyze the high-priority root causes
Define Relationships (3): Identify potential root causes, prioritize potential root causes, analyze the high-priority root causes
Estimate Costs (3): Identify potential root causes, prioritize potential root causes, analyze the high priority root causes
Determine Best Opportunities (3): Identify potential root causes, prioritize potential root causes, analyze the high-priority root causes
Group Similar Ideas (3): Generate solutions to make the process leaner, determine ways to eliminate waste, determine ways to sustain waste elimination
Establish Idea Champion (3): Generate solutions to make the process leaner, determine ways to eliminate waste, determine ways to sustain waste elimination
List Advantages and Disadvantages (3): Generate solutions to make the process leaner, determine ways to eliminate waste, determine ways to sustain waste elimination
Conduct Life-Cycle Cost Analysis (3): Generate solutions to make the process leaner, determine ways to eliminate waste, determine ways to sustain waste elimination

While Figure 8 is useful for comparing the two methodologies, its primary purpose is to identify areas that have the greatest opportunities for synergy. Stipulations and limitations of the cross-reference include the following:

- Not every study executes every step explicitly.
- The order of the steps may differ in practice.
- The steps can be performed recursively.
- The rigor of analyses varies in practice.

The tools used for analysis may be different. LSS uses many more statistical analysis tools while DFSS tools have a probabilistic focus. VE's toolset is more mechanistic in nature. Appendix B lists commonly used tools for the three approaches.

Consequently, the cross-referencing shown in Figure 8 is not absolute. Nevertheless, the mapping does demonstrate some important points. In some areas, the methodologies

- Are similar,
- Have different levels of detail, and
- Take a different perspective.

The differences do not imply that one methodology is better than the other nor do they imply weaknesses. Instead, they indicate opportunities where both approaches can be used together to achieve better results.

B. How VE Can Benefit From LSS

When LSS establishes goals in the Define Phase, customer communication tools such as Likert scales, surveys, interviews, and focus groups are used. The VE counterpart, "Prioritize Issues," is more focused on potential gains and the feasibility of implementation. More formalized customer communication would help with decision-maker acceptance and approval of VE-generated recommendations.

LSS has a more detailed front-end process for data collection. Whereas the VE methodology simply states that the data should be collected, LSS creates and analyzes process maps, determines and prioritizes measurement systems, and establishes a formal data-collection plan.[54] When VE finalizes the problem and facts in its Information Phase, it often uses QFD to obtain a better understanding of the data and data sources in the context of the problem. The LSS SIPOC framework is used to understand the entire process and where the problem fits in. VE's use of SIPOC could add insight to its Function Analysis Phase.

[54] The data collected is different. VE focuses on cost data. LSS focuses on process performance.

LSS also has a more disciplined approach toward implementation. VE simply creates an implementation plan and follows typical best practices to execute it. The LSS control plan is a formal activity to ensure that execution proceeds as planned, with specific metrics identified in advance. Furthermore, LSS includes a formal corrective action plan (sometimes as a separate process), which is not an unambiguous part of the VE methodology.

These differences represent areas in which incorporating some LSS features would likely improve the VE methodology. These synergies would help formalize the VE process to reduce the likelihood of overlooking important information needed to help determine a course of action. They would also improve the likelihood of successful implementation.

A VE continuous process improvement project, conducted on August 3, 2009, by the Defense Supply Center Columbus (DSCC), provides an example of how the more structured LSS data-collection process can help improve the VE methodology. DSCC uses VE to identify alternative lower cost suppliers for the items it manages for the Services. The process is data intensive. First, research is conducted to determine candidate items with a high potential for cost reduction through the development of new sources. Second, functional information on the item (e.g., drawings, specifications, stock samples, special markings) is collected to determine whether potential new sources are qualified and interested in bidding.

The data-collection process used by DSCC VE analysts was not well defined. Data sources were not standardized. Electronic data-collection tools were not consistently used. Therefore, the LSS project objective was to increase the likelihood of successfully qualifying alternative sources by improving the data selection tools, sources, and collection processes for identifying candidates. Activities during the LSS project phases were as follows:

- **Define.** The problem statement and business case for action were developed. The team was formed, and the expectations were established.
- **Measure.** The process value stream map was created, and metrics were defined.
- **Analyze.** Issues with the "as is" process were listed, along with associated explanatory comments, suggested improvements, and expected results for implementing the suggested improvements.
- **Improve.** Recommendations were sorted by payoff potential and ease of implementation. A prioritized list was developed, and an implementation plan was drafted.
- **Control.** Plans to reviews the effects of recommended changes were established to ensure that they were being implemented and were achieving the expected results.

These activities transformed an ill-defined VE data-collection process into one that follows a standardized and robust data-collection process formulated by developing and analyzing process maps to prioritize measurement tasks. Similar benefits can be achieved in other VE applications.

C. How LSS Can Benefit from VE

VE and LSS develop solutions to problems from different perspectives. Some of the most important distinctions are as follows:

- VE explicitly considers cost by collecting cost data and using cost models to make estimates for all functions over the life cycle. LSS reduces cost by eliminating waste and reducing variation through the use of statistical tools on process performance data. Exclusive emphasis on waste can be contradictory to reducing life-cycle cost. In VE, some waste can be tolerated if it is necessary to achieve a function that reduces the life-cycle cost. Safety stock to mitigate occasional supply disruption is a good example.
- In determining what should be changed, VE's function analysis identifies areas that cost more than they are worth, while LSS identifies root causes of problems or variations. VE's separation of function from implementation forces engineers to understand and deliver the requirements.
- For required functions that cost more than they are worth, VE uses structured brainstorming to determine alternative ways of performing them. LSS brainstorms to identify how to fix the root causes. Because functional thinking is not the common way of examining products or processes, VE augments the structured innovation process in a way that generates a large number of ideas. Shingo[55] suggests that VE is one of the most effective techniques for attacking the fundamentals of a problem. Enormous improvements are possible by determining which functions are really required and then determining how to best achieve them.
- VE develops solutions by evaluating the feasibility and effectiveness of the alternatives. LSS emphasizes solutions that eliminate waste and variation and sustain the achieved gains. VE eliminates waste in a different way. VE separates the costs required for basic function performance from those incurred for secondary functions to eliminate as many non-value-added secondary functions as possible, improve the value of the remaining ones, and still meet the customer requirements.

[55] Shigeo Shingo, "Study of the Toyota Production System from Industrial Engineering Viewpoint" (Tokyo, Japan: Japanese Management Association, 1981).

- An LSS focus on quick wins may preclude an in-depth analysis of the situation. Without analysis, projects can suboptimize or even work in opposition to one another. Using function analysis should prevent this suboptimization.

A systems engineering approach to problem solving involves analyzing the system as a whole. The major components should be understood individually and collectively in an operational construct. Then, the system can be decomposed to understand proposed changes using function analysis.[56] Problems can occur if this approach is not followed, as the following real example illustrates.[57]

The Navy's Standard Missile is a surface-to-air defense weapon. Its primary mission is fleet area air defense and ship self-defense. It also has a secondary anti-surface ship mission. It uses a mirror for celestial navigation. At one point in time, the supplier of the one-piece mirror being used announced the phase-out of the current product. The one-piece mirror was replaced with a three-piece mirror that reduced the unit price, provided the same performance, and was readily available.

Unfortunately the three-piece mirror had different mass properties than the one-piece mirror it replaced. The firmware for the guidance section had built-in compensation factors for the mirror's mass properties, and, with the new mirror, it was compensating for the wrong measurements. This problem led to a costly shutdown of the production line until the problem was fixed.

Since certain problems can be more readily, effectively, or thoroughly managed by using LSS, VE, or both, the full range of options for solving the problems should be explored. The next chapter summarizes what the recent VE literature says on opportunities for collaboration and the benefits of integration.

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[56] A systems level FMEA also provides useful insight.

[57] James R. Vickers and Karen J. Gawron, "A Systems Engineering Approach to Value Engineering Change Proposals," paper presented the 2009 DMSMS Standardization Conference (Orlando, FL, September 21–24, 2009).

5. Opportunities for Synergy

A. Literature Review

VE and LSS have limitations, but synergizing the two methodologies optimizes similarities and provides the potential to overcome their unique limitations. The literature on LSS and VE[58] analyzes the strengths and weaknesses of the methodologies and highlights opportunities for collaboration. The literature examining these methodologies points to two primary areas where VE can contribute: scope and creative tools such as the FAST diagram. Experts are encouraging in their assessments about the prospects for synergizing the methodologies. As noted by Charles L. Cell and Boris Arratia of the U.S. Army Joint Munitions Command, "VE, Lean, and Six Sigma can work effectively, independent of the other methods, but they work better together, particularly in a process where a team can take advantage of respective strengths and avoid respective weaknesses."[59]

1. Analysis of LSS

The literature identified two primary areas for improvement of LSS: scope and the creative toolkit. As Kirkor Bozdogan of MIT notes, Six Sigma lacks a "wide array of conceptually grounded and differentiated tools. Six Sigma discussions of change initiatives are designed to be quite localized and process specific."[60] Six Sigma's ability to identify and eliminate variation is useful for small-scale projects; however, it typically limits its examination of the life cycle in accounting for value. As a result, Six-Sigma-based solutions are often narrow and project specific. Lean also has limitations in the scope of its solutions. While Lean is useful in identifying problems in existing products/ processes, it is less applicable in developing new designs or solutions. Cell and Arratia note that "Lean principles and practices offer no direct method of addressing product design."[61] They also point out that Lean's success is often limited to high-value and high-cost projects that have sufficient management attention and support, including resources,

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58 Referred to by some as "Value Methodology" (VM).

59 Charles L. Cell and Boris Arratia, "Creating Value With Lean Thinking and Value Engineering" (Rock Island, IL: U.S. Army Joint Munitions Command, 2003), 8.

60 Kirkor Bozdogan, "Lean Aerospace Initiative: A Comparative Review of Lean Thinking, Six Sigma, and Related Enterprise Change Models," Center for Technology, Policy, and Industrial Development, (Cambridge, MA: MIT, December 3, 2003), 9.

61 Cell and Arratia, 3.

to implement Lean recommendations.[62] However, that assessment is not to suggest that Lean and Six Sigma are lacking in unique strengths.

One of Six Sigma's greatest strengths is its use of data. Gordon Johnson of the International Truck and Engine Corporation argues that "The Six Sigma discipline allows an organization to make use of data through statistical analysis. It qualifies and quantifies the effectiveness of an operation and gives a means to continually improve the operation."[63] These strengths highlight ways in which Lean and Six Sigma could synergize with VE. Six Sigma's collection techniques and use of data would contribute to Lean and VE studies. Henry Ball concludes that "As Six Sigma processes are data driven, the information derived is excellent input for a VM study."[64] Johnson also notes that Six Sigma's data and statistical methodology would be "useful in identifying problem areas as well as providing a way to quantify the functional impact of VM workshop proposals."[65]

As previously noted, Lean's broad approach in identifying waste is one of its greatest strengths and has the potential to contribute significantly to a VE study. Bozdogan argues that "Lean thinking provides an overarching intellectual architecture for the various systemic change initiatives, wherein they augment each other in significant ways and represent mutually complementary approaches."[66] One of Lean's greatest contributions is the value stream map. The map includes detailed information about the process and is an effective tool for identifying areas of waste that have the greatest potential to improve effectiveness and efficiency and thereby create value.[67] Lean is particularly well aligned with VE because of the customer and value focus of both methodologies. As Cell notes, "Creating value is at the core of Lean. Creating value is at the core of Value Engineering. Lean and VE use different approaches to accomplish the same objective. Assuming we accept the idea that no one approach is superior … there may be concepts, approaches, and tools in each approach that could help the other."[68]

John Sloggy comes to a similar conclusion from a product-development perspective. He states that "the best approach is to utilize the appropriate technique at the correct point

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[62] Ibid.

[63] Gordon S. Johnson, "Conflicting or Complementing? A Comprehensive Comparison of Six Sigma and Value Methodologies," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003), 5–6.

[64] Henry A. Ball, "Value Methodology—The Link for Modern Management Improvement Tools," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003), 7.

[65] Johnson, 7.

[66] Kirkor Bozdogan, "Lean Aerospace Initiative: A Comparative Review of Lean Thinking, Six Sigma and Related Enterprise Change Models," Center for Technology, Policy and Industrial Development, (Cambridge, MA: MIT, December 3, 2003), 2.

[67] Charles L. Cell and Boris Arratia, "Creating Value with Lean Thinking and Value Engineering" (Rock Island, IL: U.S. Army Joint Munitions Command, 2003), 10.

[68] Ibid., 6.

in the product/project development cycle, as opposed to force fitting a specific process across all phases of the cycle."[69] He further describes places where LSS has limitations. "Lean Manufacturing, Six Sigma and TOC address the labor and variable overhead segments of the cost structure but have little or no impact on material cost, the largest segment of the pie. For the most part, design features of the product drive material and process costs, and the Lean/Six Sigma/TOC methodology offers little in the way of a tool kit for paring these costs. Because design features drive material and process costs, a comprehensive improvement effort must attack the material cost embedded in the product design. Supply chain development programs will reduce price (and material cost) to a degree, but these efforts will always be limited by the underlying characteristics of the product design."[70]

2. Potential VE Contributions

In a 2003 presentation to SAVE, Dr. Michael J. Cook identified six ways in which VE could contribute to Six Sigma: generate project ideas, develop business strategy, define problem/defect, identify root causes, generate improvements, and generate design concepts.[71] This study, which examines both Six Sigma and Lean, will focus on what makes VE unique as compared with LSS and what VE tools would be particularly useful in conjunction with an LSS project.

VE is rich in opportunities and vision to broaden the scope of an improvement project. By examining the value of every function, VE captures a broad picture of a process while also offering solutions that will not detract from the customer-identified areas of highest value. In the Orientation Phase, Cell notes that "VE's value approach and tools help teams focus on the high payoff areas first and will generate larger savings sooner than you might otherwise get in Lean."[72] Similarly, in the Creative, Evaluation, and Development Phases, the methodology "offers analysts an effective analytic method for developing design changes to reduce cost and increase value."[73]

Based on the literature, the FAST diagram is one of the strongest elements in the VE toolkit and has the greatest potential to contribute to LSS. FAST is the primary tool for gaining a broad perspective and identifying areas of improvement within an LSS project. The FAST diagram asks *why* and *how* questions that otherwise would be explored only

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[69] John E. Sloggy, "The Value Methodology: A Critical Short-Term Innovation Strategy That Drives Long-Term Performance," in *SAVE International 48th Annual Conference Proceedings* (Reno, NV, June 9–12, 2008), 4.

[70] Ibid.

[71] Cook, Michael J., "How to Get Six Sigma Companies to Use VM and Function Analysis," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003), 4.

[72] Charles L. Cell and Boris Arratia, "Creating Value with Lean Thinking and Value Engineering" (Rock Island, IL: U.S. Army Joint Munitions Command, 2003), 5.

[73] Ibid., 3.

on a more limited basis in an LSS project, as noted by Theresa Lehman and Paul Reiser of The Boldt Company.[74] FAST is useful in almost all phases of the DMAIC and DFSS processes, particularly in the Define and Improve Phases. FAST can provide a comprehensive view of an organization and break down processes based on functions and areas of the highest value. Focusing on functions ensures that high-value areas will be remedied for efficiency and effectiveness and wasting resources will be avoided. The literature also highlights the potential to apply FAST in the Design Phase. Ball presents a theoretical application of FAST within an LSS project: Lean principles identify wasteful activities in the production of a very complex part, FAST identifies the most valuable aspects of the part and its production, and FAST is used as a creative tool to make the complex part more producible.[75]

In discussing how FAST, coupled with creative techniques and supporting exercises, drives innovation, Sloggy argues that "Innovation is what separates high-performing organizations from the rest of the pack. Value Management provides the vehicle to accelerate past the competition and reestablish dominance in business. It is the right tool for the times, and, utilized in conjunction with the Six-Sigma/Lean/TOC quality focus, it provides a viable solution to today's intensive competitive challenges. From a public sector standpoint, the same benefits of a creative approach to problem solving provide unique solutions that are cost effective in these times of dwindling resources and conflicting priorities."[76]

B. Observations and Analysis on Synergies[77]

Based on the IDA authors' comparison of the methodological approaches and the examples of synergies discussed in the literature, we conclude that VE techniques are sometimes better equipped to lead to improvements or solutions complementary to those identified through a DMAIC/DFSS approach. These synergistic opportunities derive from the different perspective that VE takes in its Function Analysis and Creative Phases as

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[74] Theresa Lehman and Paul Reiser, "Maximizing Value and Minimizing Waste: Value Engineering and Lean Construction," in *SAVE International 44th Annual Conference Proceedings* (Montreal, Quebec, July 12–15, 2004), 2.

[75] Henry A. Ball, "Value Methodology—The Link for Modern Management Improvement Tools," in *SAVE International 43rd Annual Conference Proceedings* (Scottsdale, AZ, June 8–11, 2003), 4.

[76] John E. Sloggy, "The Value Methodology: A Critical Short-Term Innovation Strategy That Drives Long-Term Performance," in *SAVE International 48th Annual Conference Proceedings* (Reno, NV, June 9–12, 2008), 6.

[77] Some of the ideas in this section were derived from suggestions made by members of the Target Costing Best Practice Special Interest Group of the Consortium for Advanced Management International (CAM-I) in response to the discussion briefing: Jay Mandelbaum and Heather Williams, "Synergy in Enterprise Change Models: Opportunities for Collaboration Between Value Engineering and Lean/Six Sigma," (March 8, 2010).

compared to the Analyze and Improve Phases in DMAIC. Table 2 illustrates the differences in perspectives by showing the goal, focus, scope, change process, and business model for VE and the three components of LSS—lean, six sigma, and TOC.[78]

Table 2. Comparison of VE and LSS Philosophical Approaches to Change

	VE	Lean	Six Sigma	TOC
Goal	Lower life-cycle cost and improve return on investment (ROI)	Eliminate waste	Reduce business risk[79]	Eliminate bottlenecks
Focus	Function analysis and function worth	All enterprise processes and people	All sources of product/variation	Throughput
Scope	Enterprise	Enterprise value stream	Enterprise	Enterprise
Change process	Incremental product/process improvement	Evolutionary and systematic	Process specific, continuous	Continuous
Business model	Increase value to the stakeholder	Deliver value to all stakeholders	Minimize waste and increase customer satisfaction	Increase financial performance of core enterprise

The differences are small in the scope, change process, and business model rows of the table. However, the distinctions revealed in the relative goals and focus can be attributed to VE's more explicit consideration of cost and more active challenging of requirements that cost more than they are worth.

In Table 2, VE's goal explicitly considers cost; consequently, VE does not sub-optimize from a financial perspective. VE only develops alternatives that provide the necessary functions, and the cost of every alternative is estimated using a cost model. The total cost estimate (life-cycle cost) is then considered (along with other things such as schedule and feasibility) in a decision-making process. If something else is being optimized (e.g., reduction in variation or waste or the elimination of bottlenecks), the effect on total cost is unclear. For example, rework costs may decrease while production costs may increase. Both VE and LSS are necessary to reduce costs—VE focuses on what is done (i.e., the function) and LSS improves it is done (i.e., with minimal waste).

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[78] Source of last three columns in Table 2: MIT, Lean Advancement Initiative

[79] The original MIT entry for this cell was "reduce variation in processes." The latest thinking is that Six Sigma is primarily concerned with process improvement, but not all process improvement is focused on variation reduction.

VE is not concerned simply with cost reduction. Its primary focus is on spending only what is necessary to meet the requirements, thereby yielding improved value and ROI. Since understanding requirements is inextricably linked to delivering functions, any alternative that provides the necessary functions in a FAST diagram will automatically satisfy the customer's requirements. An alternative that provides something beyond the necessary functions is probably providing something that is not highly valued by the customer—a cost-value mismatch. Therefore, function analysis challenges requirements by ensuring that areas of major expenditure receive attention through critical and innovative thinking about alternatives. This does not always happen by reducing variation or waste or increasing throughput. In addition, challenging the requirements discourages changing the requirements at a later time.

Figure 9 illustrates the principal areas where these differences in perspective enable VE to augment LSS efforts from a product, service, or project life-cycle perspective.

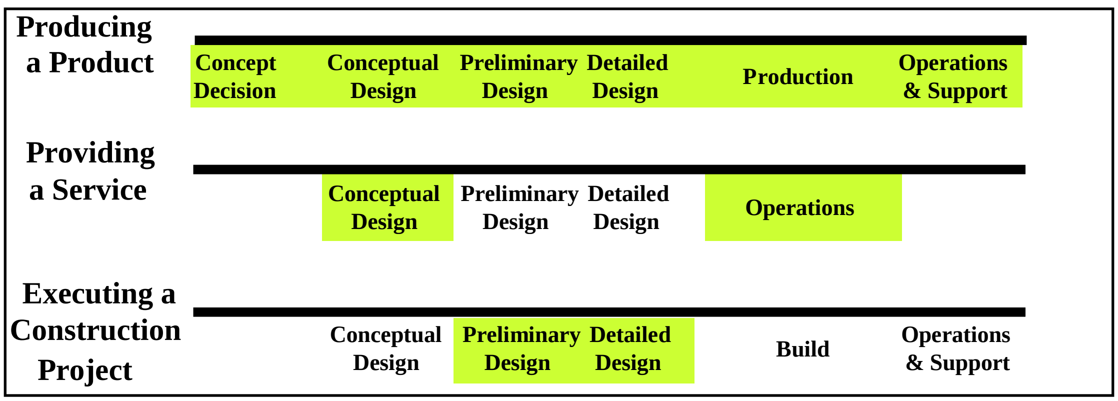


Figure 9. High-Leverage Opportunities for VE Throughout the Life Cycle

1. Synergies in Producing a Product

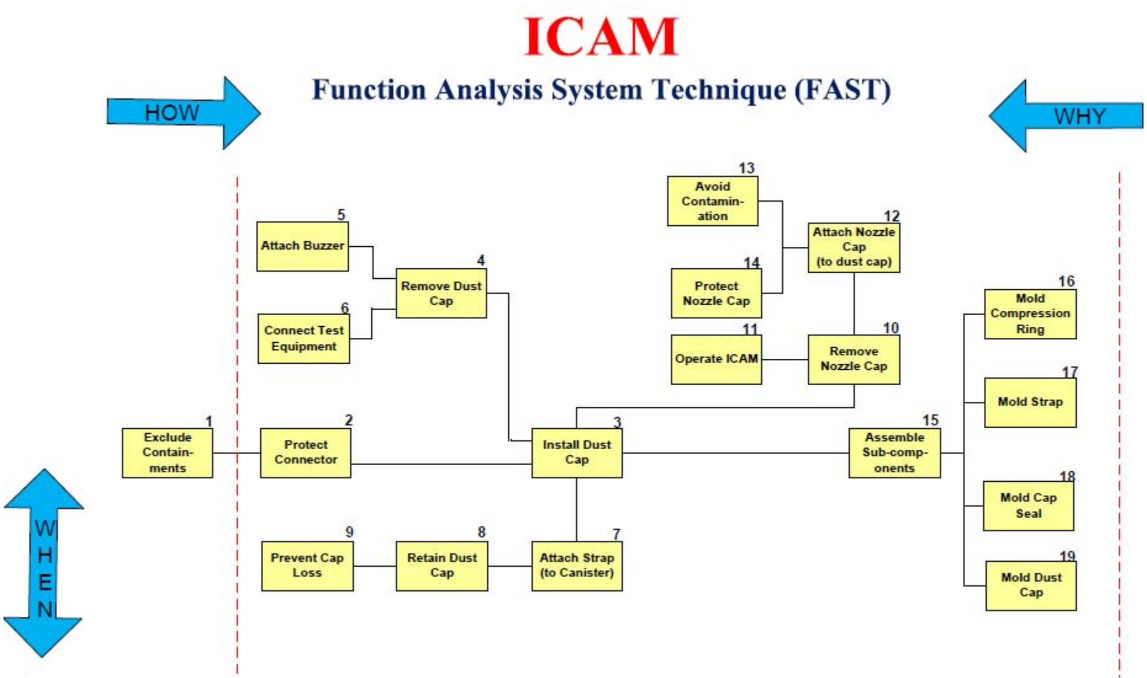
VE concepts, methods, and applications provide benefits across all phases of a product's life cycle and have been successfully applied in the DoD, where a concept decision determines an overarching approach to meet a capability need. The approach can include any combination of doctrine, organization, training, materiel, leadership and education, personnel, or facilities (DOTMLPF).[80] If a materiel solution is pursued, an Analysis of Alternatives (AoA) assesses the potential materiel solutions to satisfy the capability need.[81] By considering function and cost, a VE approach can provide important insights, and function analysis determines what must be done. Brainstorming in the Creative Phase considers all DOTMLPF options to accomplish those functions. LSS is almost never used this early in a product life cycle.

[80] See Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01G, *Joint Capabilities Integration and Development System* (March 1, 2009).

[81] DoD Instruction (DoDI) 5000.02, *Operation of the Defense Acquisition System* (December 8, 2008).

While DFSS is a proactive and anticipatory approach that helps evaluate and optimize conceptual, preliminary, and detailed designs, it is not an automatic process and does not replace skilled designers. Developing an effective design that does everything a user wants from a performance perspective and from the perspective of design considerations (e.g., supportability, maintainability, information assurance, availability, reliability, producibility may be applicable) while not costing too much or weighing too much will almost always benefit from the group perspectives and discussions of the Function Analysis and Creative Phases of the VE job plan. VE links the customer requirements to the design to manage cost. Companies worldwide integrate VE concepts into their design processes to establish target costs and ensure that unnecessary functions and requirements are eliminated.

The following simple FAST example illustrates how VE can be used in design. Figure 10 is the actual FAST diagram developed in a VE workshop for the Army's Improved Chemical Agent Monitor (ICAM). Figure 11 is a picture of the ICAM. The ICAM dust cap can be seen in the upper left corner of Figure 11. It is attached to the ICAM unit by a plastic strap.



Source: Facilitated VE Workshop, May 12–14, 2009

Figure 10. FAST Diagram for the Army's ICAM

The boxes numbered 4–6 and 10–14 in Figure 10 described how the ICAM is operated. When the dust cap is removed to use the ICAM, it should remain attached by the plastic strap. The installation of the dust cap is shown in boxes 3 and 7–9 in Figure 10.

Figure 11. Improved Chemical Agent Monitor (ICAM)

The problem being experienced in the field was that the strap was prone to breaking, and, when that happened, the dust cap was usually lost. Replacing the dust cap is costly since the strap, dust cap, compression ring, and seal are a single plastic-injected part (see boxes 15–19 in Figure 10). To correct this problem, 36 ideas were developed during the VE brainstorming session. Two of them were developed further: (1) make the strap a separate part and (2) use coated braided wire for the strap and attached it to the dust cap assembly with a rivet.

VE has little to add to LSS in improving manufacturing processes on the production floor; however, VE can contribute to the production phase of a product's life cycle in other ways. Production costs can often be reduced by introducing new technologies, new processes, new materials, and/or new designs. The VE methodology can more readily identify creative problem-solving approaches than LSS, especially in government contracts.[82]

A real-world example of this is the Phalanx Close-In-Weapon-System (CIWS), a fast-reaction, rapid-fire 20-mm gun system that provides Navy ships a terminal defense against anti-ship missiles and fixed-wing aircraft that have penetrated other fleet defenses. Phalanx uses advanced radar and computer technology to locate, identify, and

[82] While the government encourages both VE and LSS, some special implementation requirements are associated with VE. In 1993, OMB Circular A-131 mandated the use of VE by all federal agencies and also required annual reporting on VE savings. This mandate was reinforced by the National Defense Authorization Act of Fiscal Year 1996 (Public Law 104-106, Section 4306), which stated that "Each Executive Agency shall establish and maintain cost-effective value engineering procedures and processes." It defined VE as "an analysis of the functions of a program, project, system, product, item of equipment, building, facility, service, or supply of an executive agency, performed by qualified agency or contractor personnel, directed at improving performance, reliability, quality, safety, and life-cycle costs."

direct a stream of armor-piercing projectiles to the target. A contract was awarded to retrofit Phalanx with a manual controller to direct fire against targets of opportunity. Using the Function Analysis Phase of the VE methodology, the contractor identified an opportunity to replace a military standard fixed-hand controller (similar to a joy stick) with a derivative of a commercial unit not built to military standards.[83] The contractor, on its own initiative, worked with the commercial source to produce a modified unit and tested the unit against the requirements for the military standard version. Based on the test results, the contractor had confidence that the commercial derivative would meet all of the technical requirements at a lower cost. Therefore, the contractor submitted a Value Engineering Change Proposal (VECP)[84] to replace the standard military controller with ruggedized commercial derivatives. The military standard controller cost $7,600. The commercial derivative cost only $2,100. Since each gun required three controllers, the net savings would be $16,500 per system. The U.S. Navy and the contractor shared approximately $2 million in savings. Eventually, the Navy can save more than $9 million if the idea is applied to all ships. In addition, the VECP provided for earlier implementation of the improved system.

This example illustrates a second point. The VE methodology can develop additional alternatives, and the contractual use of VECPs with the government can create incentives for the contractor to develop new ideas, thereby creating further opportunities for synergy.

VE can also attack variation in production differently than LSS. For example, when Alan Mulally became CEO of Ford Motor Company in 2006, he targeted unnecessary and costly product variations that contributed no value to the customer. The following anecdote was not actually a VE application, but it illustrates the kind of solution that might be derived from VE. According to *The Wall Street Journal*, Mulally "laid out 12 different metal rods that Ford uses to hold up a vehicle's hood. He wanted to demonstrate to managers that this kind of variation is costly but doesn't matter to customers."[85]

In the operations and support phase of the product life cycle, VE and especially VECPs provide additional opportunities to enhance LSS-developed options. Within the

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[83] This example illustrates the power of function analysis in indentifying alternative (less costly) ways to perform required functions.

[84] VE has two implementation mechanisms. A Value Engineering Proposal (VEP) is a specific proposal developed internally for total value improvement from the use of VE techniques. Since VEPs are developed and implemented internally, all resulting savings accrue to the implementing organization. A VECP is a proposal submitted to the government by the contractor in accordance with the VE clause in the contract. A VECP proposes a change that, if accepted and implemented, provides an eventual, overall cost savings to the government. The contractor receives a substantial share in the savings accrued as a result of implementation. It, therefore, provides a vehicle through which acquisition and operating costs can be reduced while the contractor's rate of return is increased.

[85] Monica Langley, "Inside Mulally's 'War Room': A Radical Overhaul of Ford," *The Wall Street Journal*, December 22, 2006.

Diminishing Manufacturing Sources and Material Shortages (DMSMS) situation, VE concepts can identify a large number of resolution options, evaluate their potential for solving the problem, develop recommendations, and provide incentives for the investments needed for successful implementation.[86] Using the VE methodology provides greater opportunity for developing and implementing innovative solutions to DMSMS problems.

For example, a defense missile contractor had a sole-source subcontractor for a costly warhead. The subcontractor was having problems meeting "insensitive munitions capability" requirements for the warhead not to explode in a fire or if dropped. With the cooperation of the government, the contractor submitted a VECP to develop an alternative, less-expensive source for the warhead by using reverse engineering. Since a different manufacturer would be used, the performance of the warhead's insensitive munitions capability could also be improved because this manufacturer would use a different process for making the explosive portion of the warhead. Approximately $12 million is currently being invested to develop the new source. Although savings of $15,000 per warhead is expected, the development of the second source makes this VE change and development of a second source even more valuable. Without the competition from another source, the price of the warhead probably would have continued to escalate as it had in the past since the single source had no incentive to control costs.

2. Synergies in Providing a Service

VE application to the design or redesign of a service (and by analogy a process) is similar to the product situation. The following hypothetical example[87] assumes a 3-year contract (a base year plus 2 option years) for the professional services of a physician to give full physicals to 3,600 military personnel each year (i.e., 10,800 physicals (3,600 × 3)) for $100 each, for a cost of $1,080,000. The associated contract requirements reflected in Table 3 depict what a contract line item (CLIN) may look like.[88] Figure 12 is a functional analysis representation of the situation.

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[86] Jay Mandelbaum, Royce R. Kneece, and Danny L. Reed, *A Partnership Between Value Engineering and the Diminishing Manufacturing Sources and Material Shortages Community To Reduce Ownership Costs*, IDA Document D-3598 (Alexandria, VA: Institute for Defense Analyses, September 2008).

[87] Jay Mandelbaum, Ina R. Merson, Danny L. Reed, James R. Vickers, and Lance M. Roark, *Value Engineering and Service Contracts*, IDA Document D-3733 (Alexandria, VA: Institute for Defense Analyses, June 2009).

[88] This example depicts only one element of a larger contract. Obviously, some people would need more extensive medical care as a function of their physical condition. Such care would be provided in a separate CLIN. Also, depending on a person's occupation, additional assessments may be required. This example focuses only on that element of the population required to have a physical as their annual health assessment.

Table 3. Medical Service Contract Example Before VECP Changes

CLIN	Description	Quantity	Unit	Unit Price	Total Price
0001	Provide a complete annual physical to military personnel	10,800	EA	$100	$1,080,000

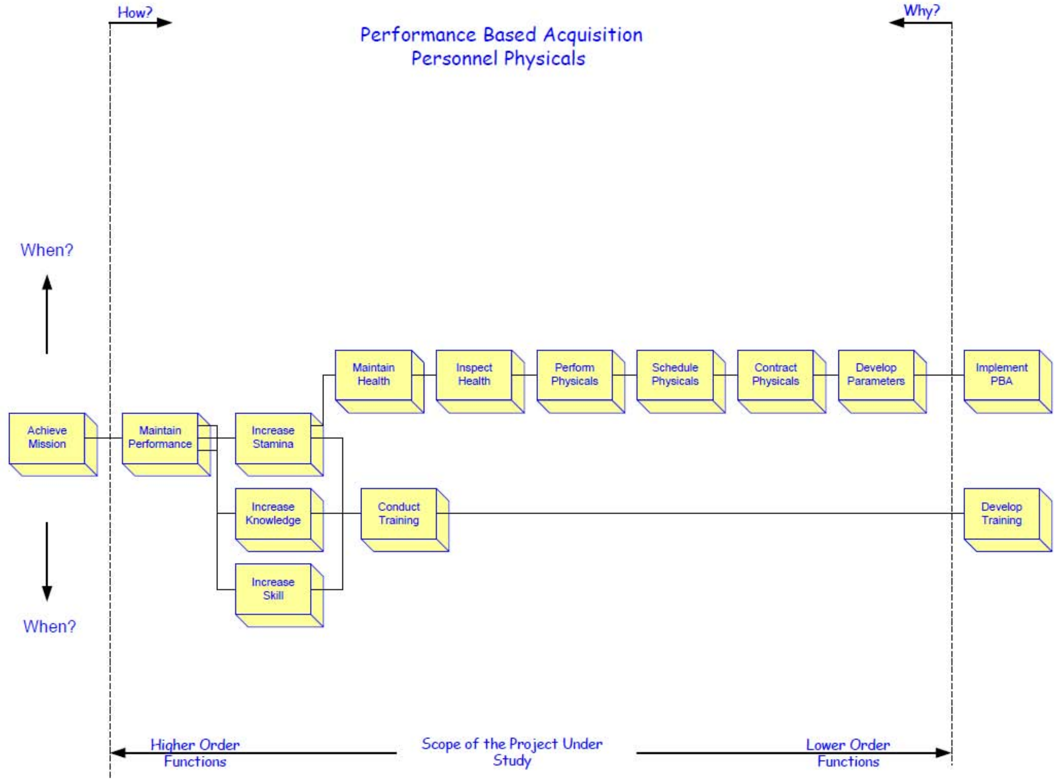

Figure 12. VE Function Analysis on a Services Contract To Provide Physicals Before a VECP

Using VE to challenge the requirements creates opportunities to improve upon LSS solutions. In the preceding example, most of these military personnel are young and in excellent physical condition; therefore, the contractor could propose a VECP for a modified physical plan. Under the plan, anyone under 25 years of age would get a complete physical every 3 years, anyone 26–35, every 2 years, and anyone over 36, every year.[89] Those personnel not given a complete physical would receive a modified physical that could be performed at a lesser cost of $50. The VECP results shown in Table 4 assume the military population is divided equally among the three age bands. Figure 13 shows the corresponding function analysis.

[89] This example is not intended to imply that the military would ask for more service than it needs. Instead, it illustrates how risk/requirements trades can be made.

Table 4. Medical Service Contract Example After VECP Changes

CLIN	Description	Quantity	Unit	Unit Price	Total Price
0001	Provide a complete annual physical to military personnel	6,000	EA	$100	$600,000
0002	Provide a modified physical to military personnel	4,800	EA	$50	$240,000
	Subtotal	10,800			$840,000
	VECP Savings ($1,080,000 – $840,000)				$240,000
	Contractor's Share of Savings Using a 50/50 share ($540,000 × .5)				$120,000
0003	New CLIN for VECP savings	10,800	EA	$25.00	$120,000
	New Contract Total				$980,000

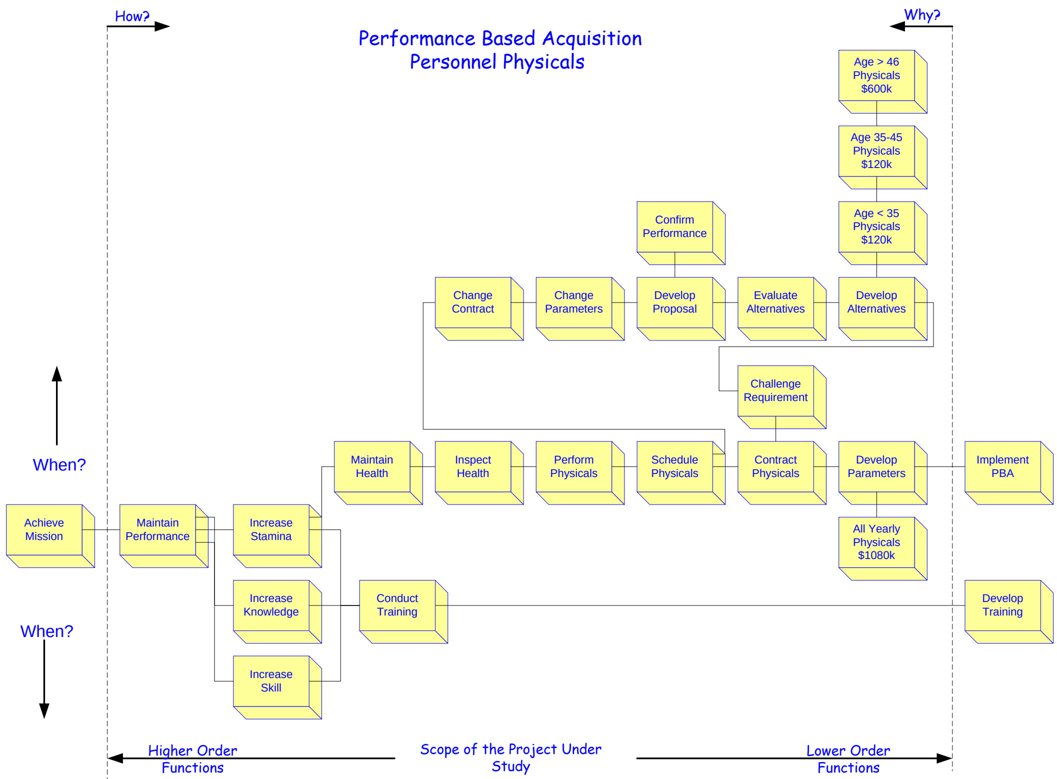

Figure 13. VE Function Analysis on a Services Contract To Provide Physicals After a VECP

Function analysis challenges requirements by questioning the existing system, encouraging critical thinking, and developing innovative solutions. It ensures that areas of major expenditure receive attention in the early stages of a service contract. The government receives substantial benefits—costs in this example are reduced by more than 10%.[90] Without VE, however, the contractor does not have an incentive to propose such a

[90] A secondary issue is that indirect rates may have to be increased if the reduction in the number of billed hours is significant.

requirements change. Since a contractor needs some incentive to perform less work, a better mechanism of compensation is needed for the contractor to propose a VECP in a service environment. When less work is performed, revenue is down, so a balance or tradeoff to increase profit must be found to make the change a worthwhile proposition for the contractor.[91] In this example, if a 10% profit is assumed, the $120,000 share of the savings appears to more than compensate for lost revenue. In the next contract, implementation of this idea would provide 100% of the savings to the government. The government also allows the contractor to receive a 10% royalty for use of his idea for the next 3 years.

3. Synergies in Executing a Construction Project

VE has the greatest potential to augment LSS when the approach and costs are known (e.g., after design definition, approved feasibility study, and early remedial design are completed). As in all of the preceding discussions, VE identifies the essential functions and derives lower cost alternative ways of accomplishing them. Both VEP and VECP approaches apply. The VE Workshop is an opportunity to bring the design team and client together to review the proposed design solutions, the cost estimate, and the proposed implementation schedule and approach, with the goal of achieving the best value for the money. The definition of what is good value on any particular project will change from client to client and project to project.

For example, VE has been used to make the following changes in DoD construction projects:

- Construct slab-on-grade in lieu of a more expensive structural slab where feasible. The former option would save money because it requires less effort and is only necessary to create a hard grade with a bulldozer. If a structural slab were needed, digging below the frost grade, leveling, and recompacting would be required to install footings.
- Combine buildings or phases of construction phases to reduce site preparation costs and allow utilities and heating, ventilation, and air conditioning (HVAC) systems to be shared.
- Use electrical generators for power peak-sharing, which would allow building occupants to stay below the peak rates. By staying below the peak rate, savings are accrued throughout the year.
- Control the HVAC system with direct digital instead of a single-loop system. Since HVAC is on a timer and a digital timer is more accurate and can have

[91] Collateral savings are also associated with the VECP depicted in Table 4. Since the modified physicals take less time, people would not be away from work as long and, therefore, would be able to perform additional duties. Since this benefit is relatively small and difficult to quantify, such collateral savings are normally not claimed.

better temperature control, this approach would eliminate overcooling, and the HVAC system would be used only when people are in the building.

- Use waste heat with recovery system. Money is saved when recycled heat generated by one process is used in another.
- Install alternative insulation behind precast concrete bonds. A concrete bond would be made in a factory and simply put in place. This could reduce labor cost and also is a faster way to apply insulation.

VECPs are more applicable when the construction project has separate design and build contracts. Contractors are provided monetary incentives to propose solutions that offer enhanced value to the government and share in the financial benefits realized. Clearly, the government must consider contractor-generated proposals carefully from a life-cycle and a liability perspective. The architect and engineer teams must part of the decision-making process to ensure that the proposed change does not have any negative impact on the overall design and building function. VECP evaluation is treated similarly to any change order during construction, with issues such as schedule and productivity impacts being considered along with the perceived cost savings generated. As a result, the functionality of the project is improved, costs are thoroughly checked and reduced over the life cycle, and a second look at the design produced by the architect and engineers gives the assurance that all reasonable alternatives have been explored.

6. Conclusions

Both LSS and VE have unique attributes and perspectives for process improvement. Since certain problems can be more readily, effectively, or thoroughly managed by using one or both of these perspectives, exploring the full range of solution options is crucial. Based on the IDA authors' comparison of the methodological approaches and the examples of synergies discussed in the literature, we conclude that in some circumstances, VE techniques are better equipped to lead to improvements or solutions that complement those identified through a DMAIC/DFSS approach. These opportunities for synergy include the following:

- **Function analysis and the FAST diagram.** The disciplined use of function analysis is the principal feature that distinguishes the VE methodology from other improvement methods. Function analysis challenges requirements by questioning the existing system, encouraging critical thinking, and developing innovative solutions.
- **Cost focus.** VE only develops alternatives that provide the necessary functions. By examining only those functions that cost more than they are worth and identifying the total cost of each alternative, VE explicitly lowers cost and increases value.

VE does not take the place of LSS efforts, but it does present significant opportunities to enhance LSS-developed options. Therefore, the IDA authors recommend that LSS training be augmented to include the VE approach to function analysis, creativity, and associated elements of evaluation and development to identify candidate solutions as part of the Analyze and Improve Phases of DMAIC.

As far as DFSS is concerned, VE tools should be explicitly used in the process. They should be used in the Analyze Phase of DMADV to construct function views of the product or process to identify customer priorities and determine functional requirements. They should also be used in the Design Phase of DMADV to generate alternative design concepts and to modify component/subsystem preliminary and detailed designs to introduce new elements to the evaluation and optimization processes.

Similarly, VE practitioners should incorporate several LSS features when they prepare for and conduct workshops. Examples include the use of

- Customer communication tools such as Likert scales, surveys, interviews, and focus groups to set goals early in the process;

- A more formalized data collection plan;
- SIPOC to add insight during function analysis;
- A control plan to ensure implementation proceeds as planned; and
- A formal corrective action plan to adapt to changes during implementation.

Appendix A.
Cross-Reference Charts in Detail

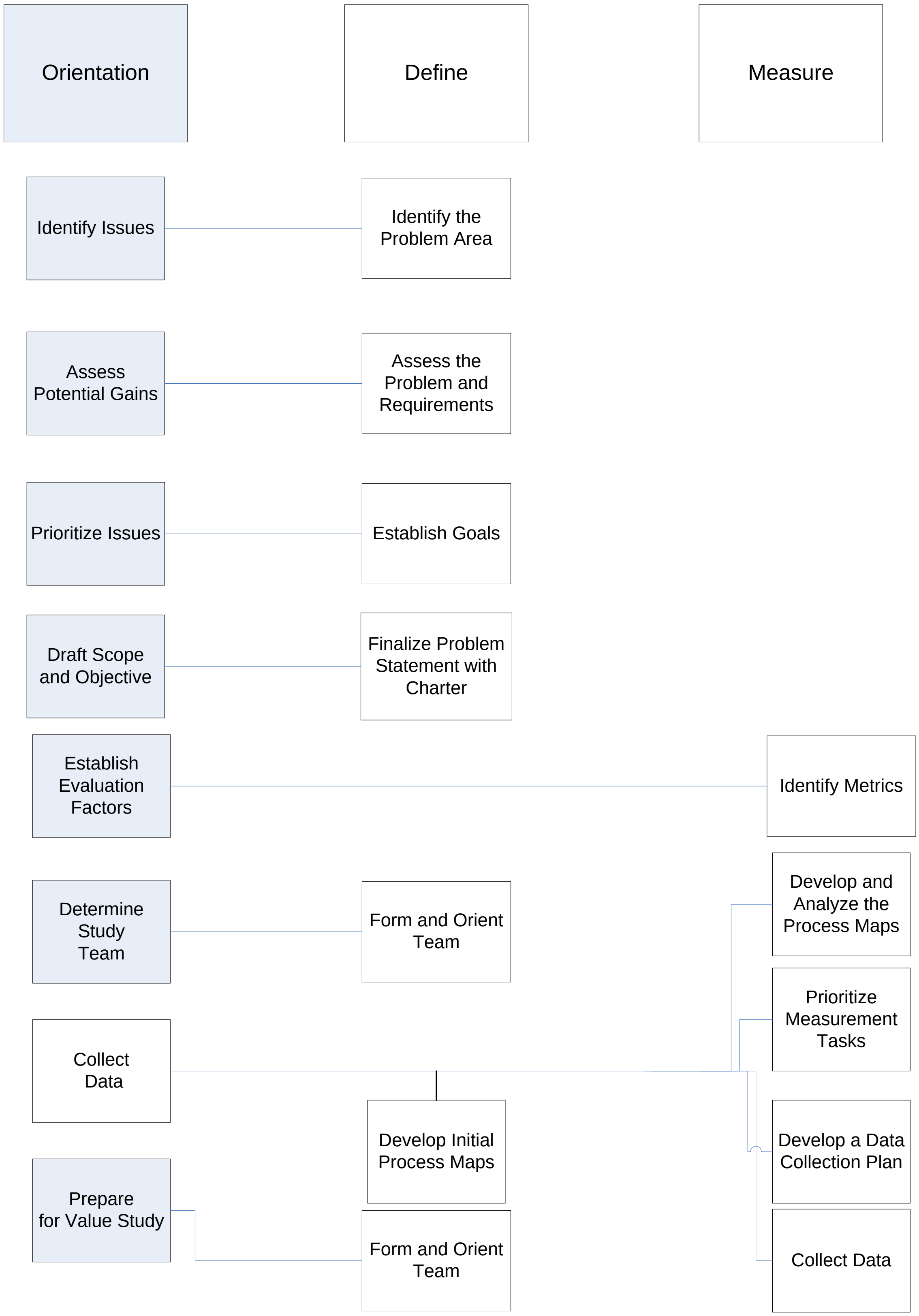

Figure A-1. Orientation Phase Cross-Referenced With DMAIC Methodology

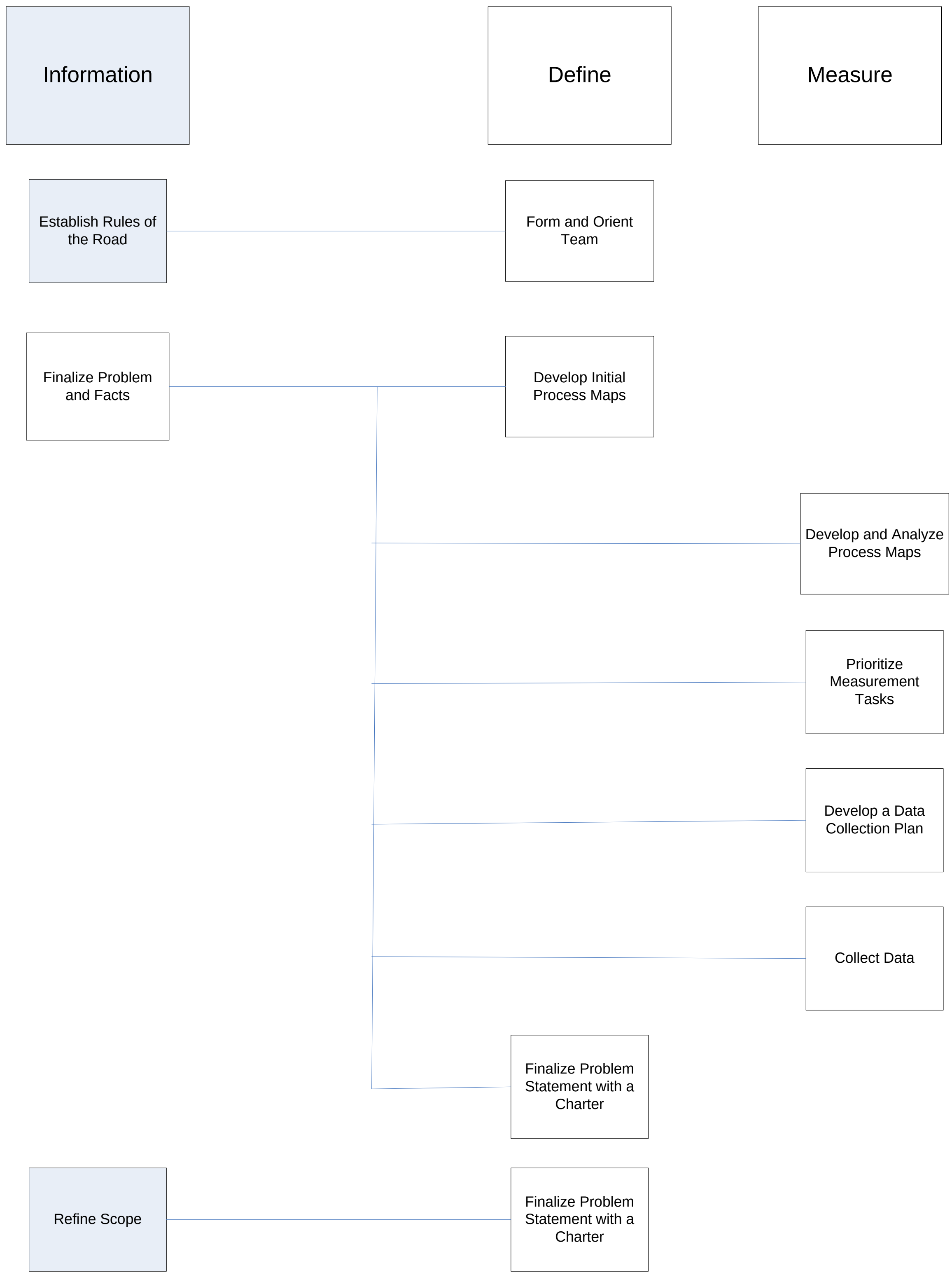

Figure A-2. VE Information Phase Cross-Referenced With DMAIC Methodology

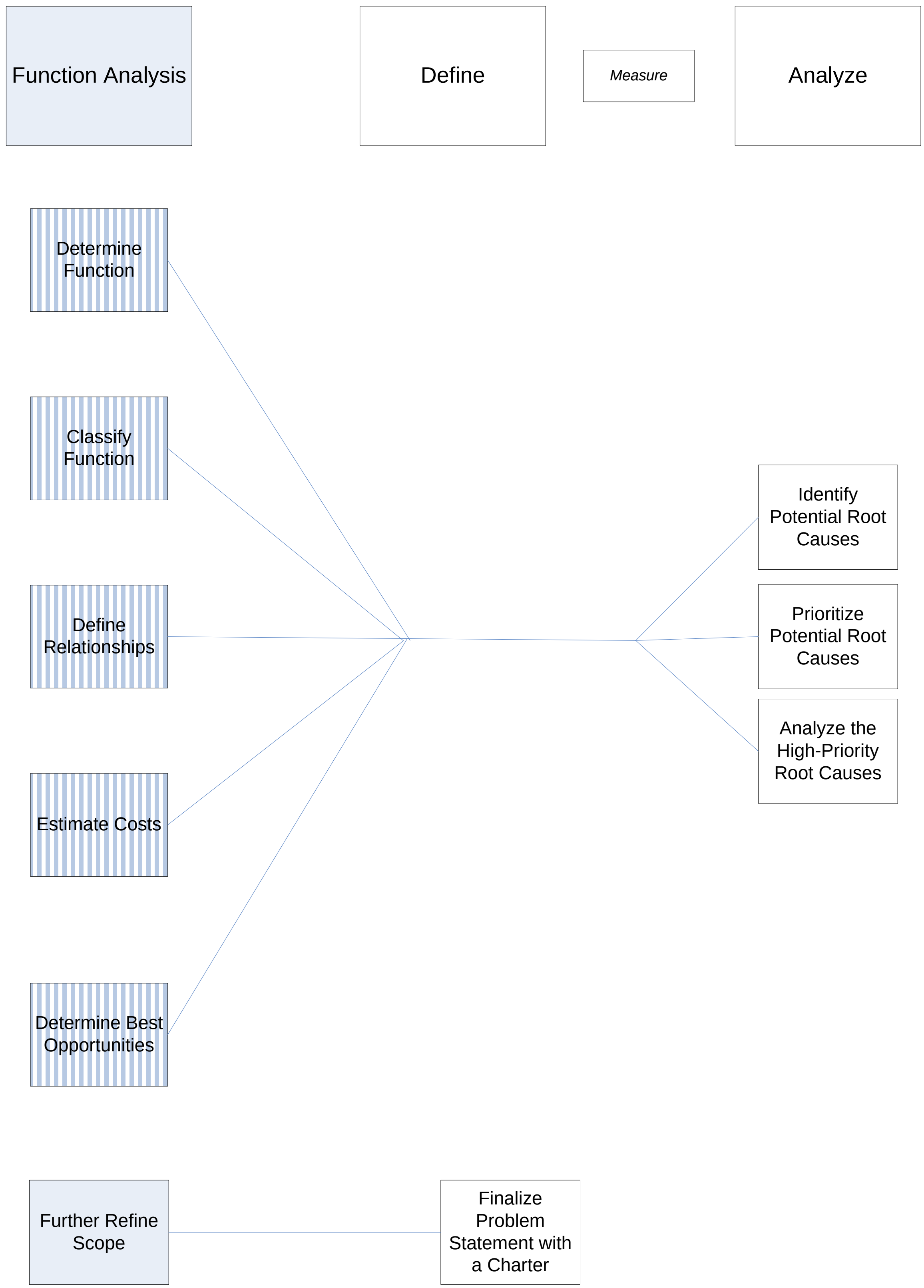

Figure A-3. VE Function Analysis Phase Cross-Referenced With DMAIC Methodology

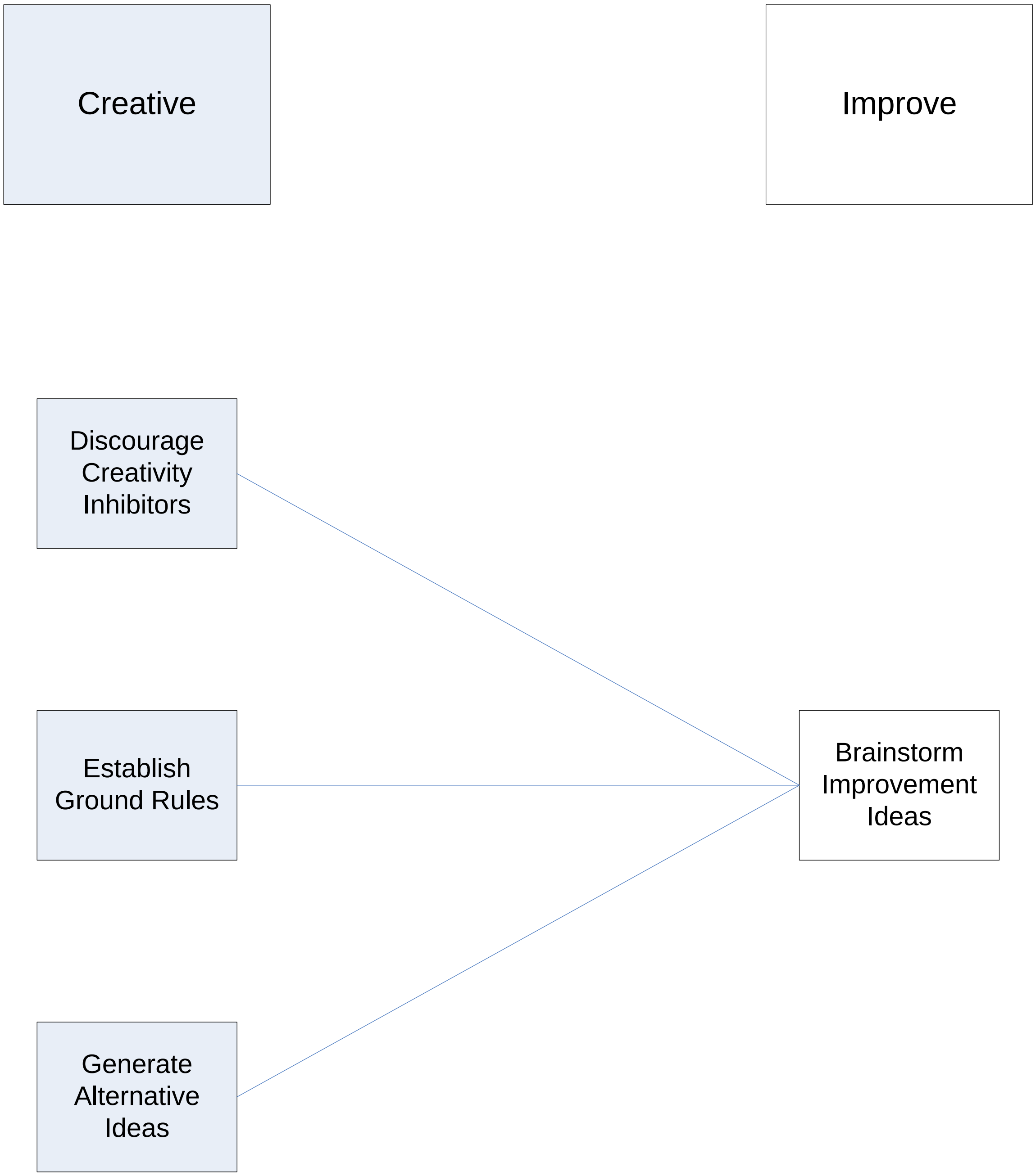

Figure A-4. VE Creative Phase Cross-Referenced With DMAIC Methodology

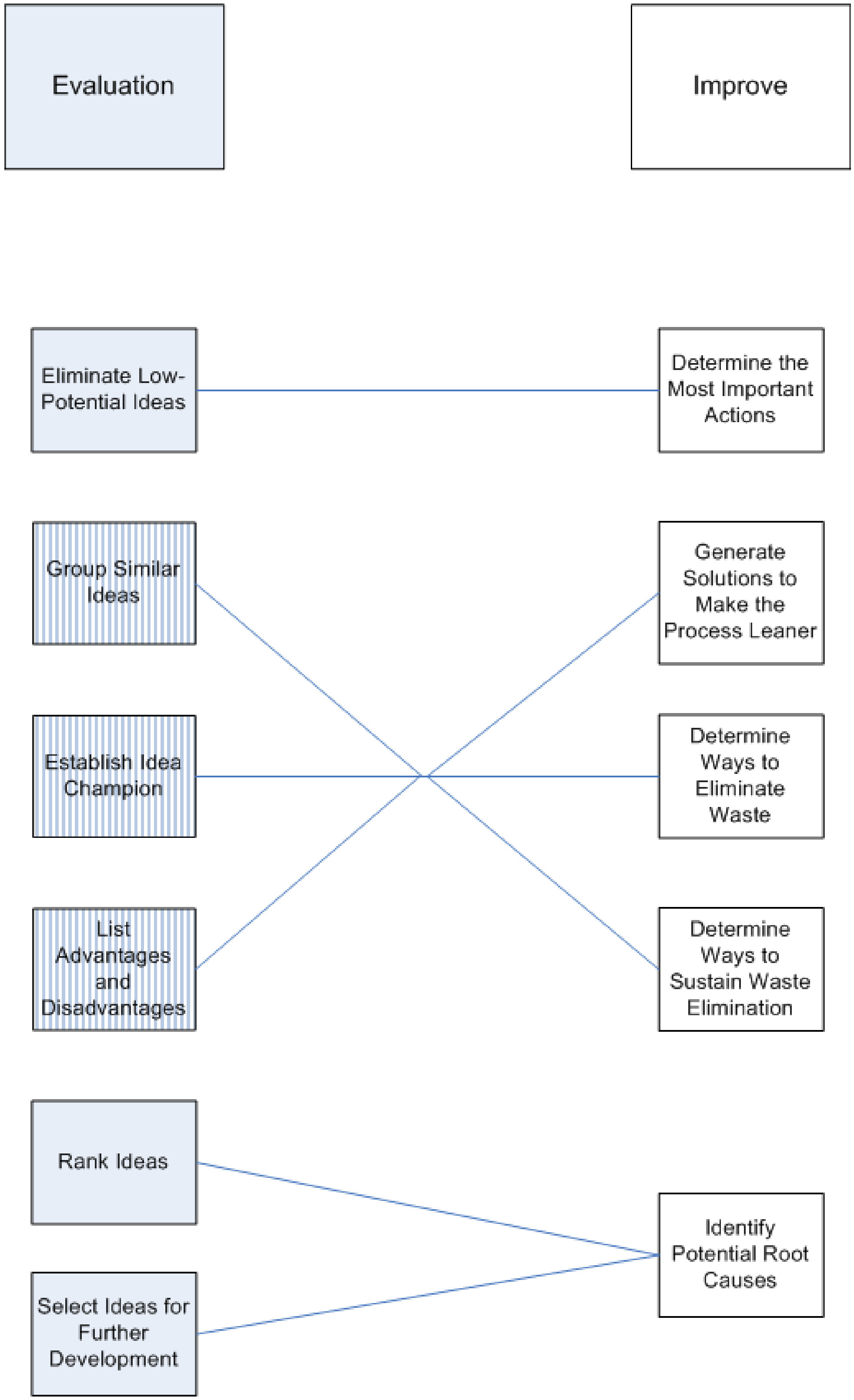

Figure A-5. VE Evaluation Phase Cross-Referenced With DMAIC Methodology

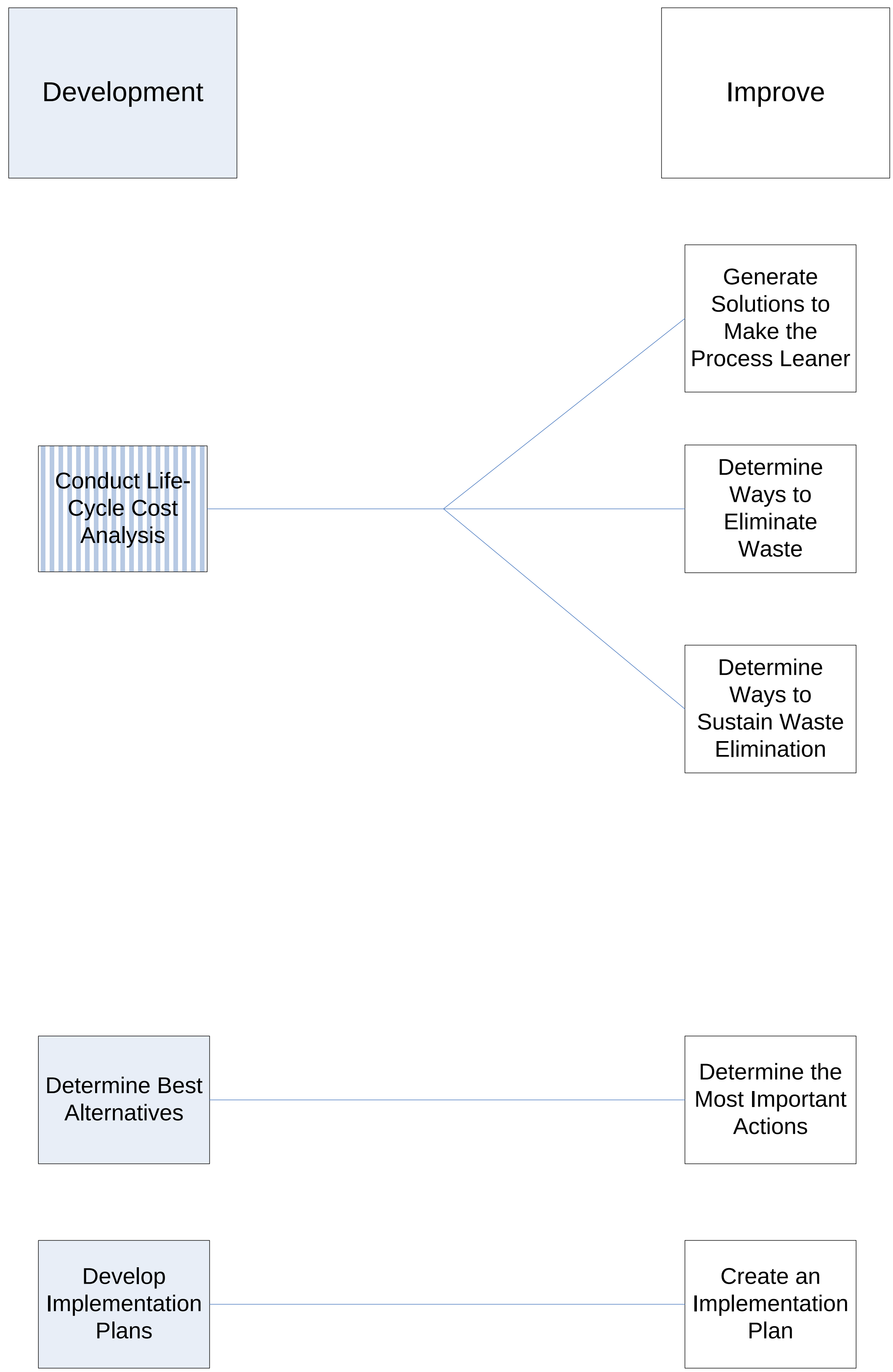

Figure A-6. VE Development Phase Cross-Referenced With DMAIC Methodology

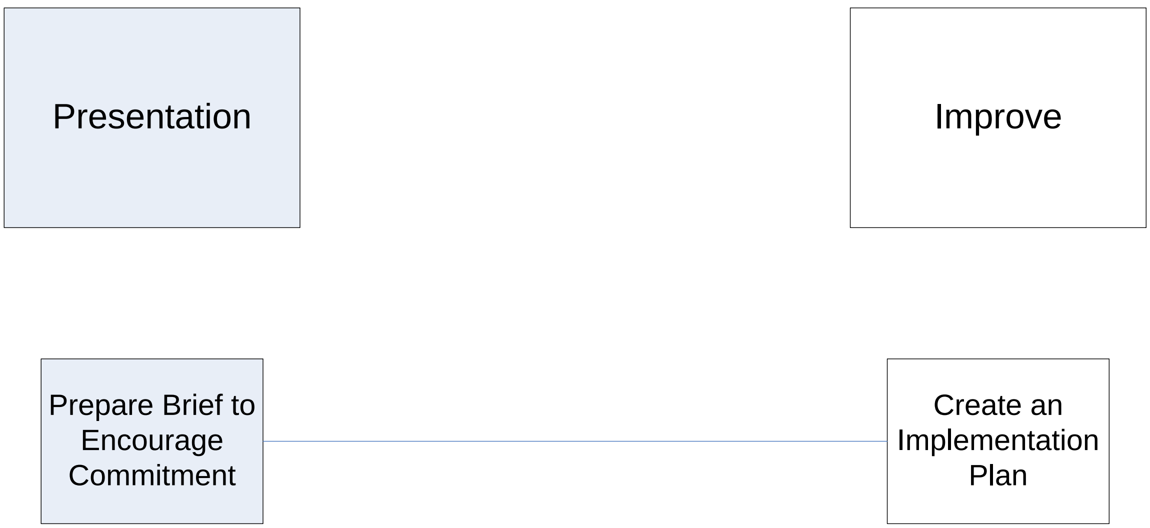

Figure A-7. Presentation Phase Cross-Referenced With DMAIC Methodology

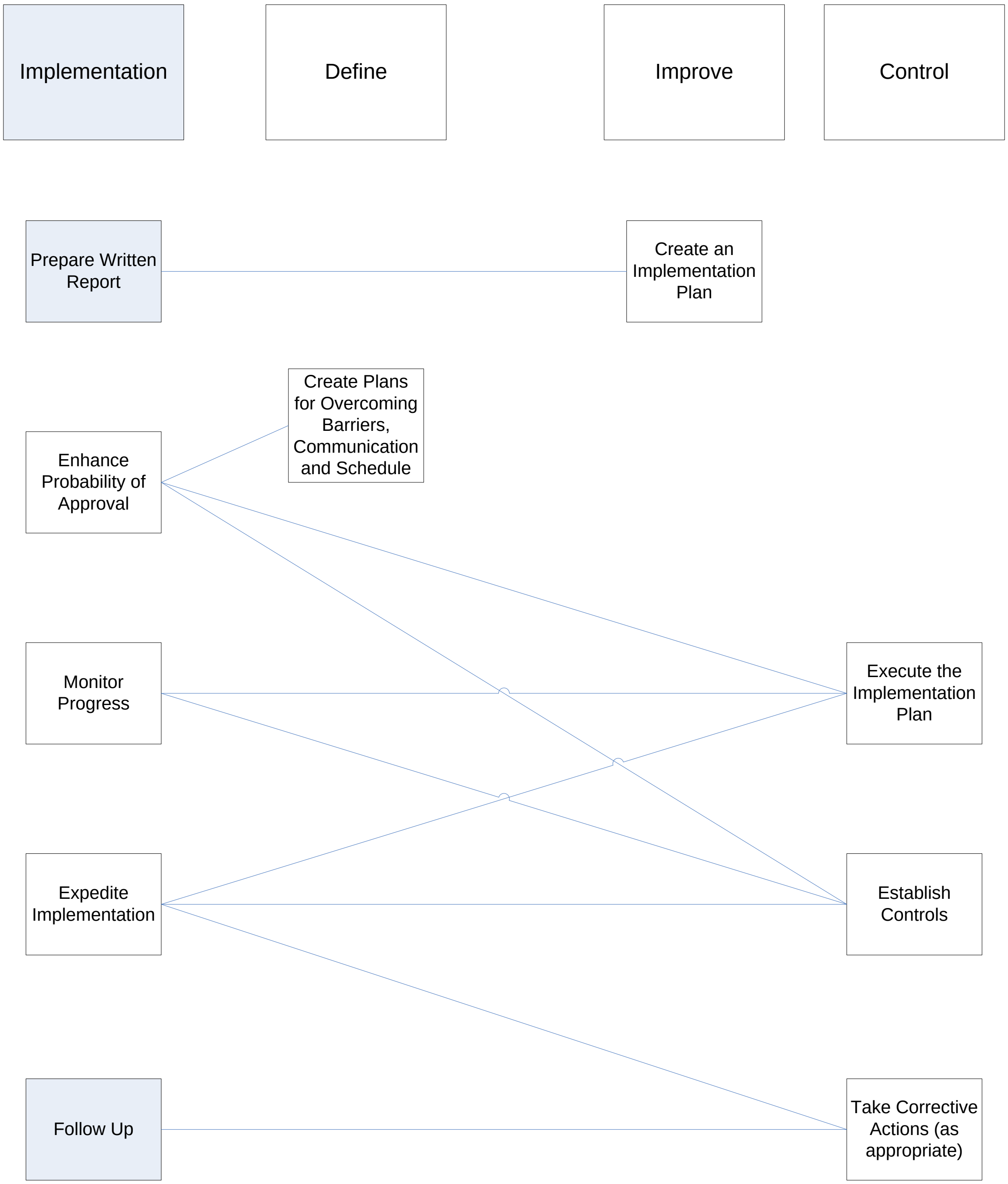

Figure A-8. VE Implementation Phase Cross-Referenced With DMAIC Methodology

Appendix B.
Common LSS, DFSS, and VE Tools

Table B-1. Common LSS Tools

Define Phase

Interviews
Focus Groups
Surveys
Focused Project Definition Tree
Top-Down Flowchart
Spaghetti Flowchart
Detailed Flowchart
Deployment Flowchart
Time Value Chart
SIPOC

Measure Phase

Quality Function Deployment (QFD)
Gage Repeatability and Reproducibility (GRR)
Short Method
Test Retest
Attribute GRR
P(Miss), P(False Alarm), Overall Effectiveness

Analyze Phase

Benchmarking
Solution Tree
Normality Plot
Histogram
Run Chart
Capability Analysis Normal
Six Sigma Process Report
Six Sigma Product Report
Solution Tree
Progressive Search
Multi-Vari Chart
One sample T
Two-Sample T
Paired T
One-Way Analysis of Variance
Homogeneity of Variance
General Linear Model
Power and Sample Size
Dot Plot
Box Plot
Pareto
Mood's Median
Runs Test
Chi-Square Minitab

Analyze Phase (Continued)

Chi-square Excel
Phi Statistic
Fisher's Exact
Binary Logistic Regression
Power and Sample Size
Scatter Plot
Correlation
Simple Linear Regression
Multiple Linear Regression
Polynomial Regression
Matrix Plot
Residual Plots
Binary Logistic Regression
Component Search
Paired Comparisons

Improve Phase

Tolerance Parallelogram
Crystal Ball Simulation
Design of Experiments
Full Factorial
Fractional Factorial

Control Phase

Failure Mode and Effects Analysis
Mistake Proofing
Control Charts
Process (Low Volume)
Pre control
Control Plan

Lean

Value Stream Map
Waste
Pull
Kanban
Takt Time
Standard Work Combination Sheet
Standard Work In Process
Material Presentation
Visual Management

Table B-2. Common DFSS Tools

Define
Multi-Generation Product Plans
Multi-Generation Technology Plans
Kano model
QFD
Customer Surveys
Affinity Diagrams

Measure
System Models
Behavior Models
Context Diagrams
Structure Tree
Critical To Quality (CTQ) Flowdown
Target Costing
Benchmarking
Measurement Systems Analysis/GRR/Calibration

Analyze
Brainstorming
Benchmarking
Pugh Concept Selection
Weibull Reliability Analysis
Systems Reliability Scorecards
Hypothesis Testing
DFSS Scorecards
Failure Mode Effects and Criticality Analysis
FMEA/FMEA Lite
Risk Assessment

Design
Design and Analysis of Computer Experiments
Design of Experiments
Metamodeling – Regression
Non-Parametric Metamodeling
Process Capability Analysis
Process Capability Databases
Material Property Databases
Data Visualization Tools – Data Mining

Optimize
Robust Design/Reliability
Optimization – Derivative Based
Optimization – Stochastic
Filtered Monte Carlo Optimization
Multi-Objective Optimization
Partial Derivatives
Monte Carlo Simulation
Fast Probability Integration
Point Estimate Method
Worst Case Tolerance Analysis
Root Sum Squares Tolerance Analysis
3D Tolerance Analysis
Error Proofing

Table B-3. Common VE Tools

Information Phase
QFD
Voice of Customer
Strengths, Weaknesses, Opportunities, and Threats (SWOT)
Project Charter
Benchmarking
Design for Assembly
Pareto Analysis
Tear-Down Analysis

Function Analysis Phase
Random Function Identification
Functional Analysis System Technique (FAST)
Function Tree
Cost to Function Analysis (Function Matrix)
Failure Models and Effects Analysis (FMEA)
Performance to Function Analysis,
Relate Customer Attitudes to Functions
Value Index

Creative Phase
Creativity "Ground Rules"
Brainstorming
Synetics
Theory of Inventive Problem Solving (TRIZ, in Russian Teoriya Resheniya Izobretatelskikh Zadatch)
Nominal Group Technique
Gordon Technique

Evaluation Phase
T-Charts
Pugh Analysis
Value Metrics
Choosing by Advantages
Life-Cycle Costing
Kepner-Tregoe

Appendix C.
Illustrations

Figures

Tables

Appendix D.
References

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Appendix E.
Abbreviations

ANOVA	Analysis of Variance
AoA	Analysis of Alternatives
AT&L	Acquisition, Technology and Logistics
CAM-I	Consortium for Advanced Management International
CIWS	Close-In-Weapon-System
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CLIN	contract line item
CTQ	critical to quality
DFSS	Design for Six Sigma
DMADV	Define, Measure, Analyze, Design (and Optimize), and Verify
DMAIC	Define, Measure, Analyze, Improve, and Control
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOE	design of experiments
DOTMLPF	doctrine, organization, training, materiel, leadership and education, personnel, or facilities
DSCC	Defense Supply Center Columbus
FAST	Function Analysis System Technique
FMEA	Failure Models and Effects Analysis
GE	General Electric
GRR	Gage Repeatability and Reproducibility
HVAC	heating, ventilation, and air conditioning
ICAM	Improved Chemical Agent Monitor
IDOV	identify, design, optimize, and verify
JIT	Just-in-Time
LSS	Lean Six Sigma
MIT	Massachusetts Institute of Technology
OMB	Office of Management and Budget
QFD	Quality Function Deployment
RACI	Responsible, Approval, Contributor, and Informed
ROI	return on investment
SAVE	Society of American Value Engineers
SIPOC	Supplies, Input, Process, Outputs, and Customers
SMART	Specific, Measurable, Achievable, Relevant, and Time
SWOT	Strengths, Weaknesses, Opportunities, and Threats

TOC	Theory of Constraints
TQM	Total Quality Management
TRIZ	Theory of Inventive Problem Solving (in Russian Teoriya Resheniya Izobretatelskikh Zadatch)
VA	Value Analysis
VE	Value Engineering
VECP	Value Engineering Change Proposal
VEP	Value Engineering Proposal
VM	Value Management
VSM	value stream mapping

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14. Abstract

Lean Six Sigma (LSS), its Design for Six Sigma (DFSS) variant, and Value Engineering (VE) were developed as business process improvement initiatives. This paper explores synergies between LSS, DFSS, and VE by identifying opportunities where they can be used together to increase the likelihood of obtaining improvements beyond the capability of just one approach.

15. SUBJECT TERMS

value engineering, value management, value analysis, lean six sigma, design for six sigma

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